Understanding Modifiable Determinants of Fatigue from a Physiological Perspective in Canadian FireRangers

by

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Abstract

Ontario FireRangers exhibit high annual injury rates and cite fatigue as a contributor, however several factors influence fatigue, including: energy expenditure, energy intake, stress levels and recovery time. The purpose of this research was to evaluate the accuracy of heart rate variability (HRV) based estimates of energy expenditure (kilocalories) and to then assess energy balance, physiological responses, and nutritional quality in Ontario FireRangers during different types of fire deployments. Firstbeat Bodyguard2 and Zephyr BioHarness3 monitors were used to collect HRV data, and individual audio-visual food logs were kept using an iPod Touch and analyzed in NutriBase Pro11 software. Sleep quantity was also measured using actisleep monitors, to assist with energy expenditure calculations. The findings of this research support the use of HRV monitoring for free-living, energy expenditure estimation. Furthermore, this research indicates that Ontario FireRangers exhibit high daily energy demands, under-consume kilocalories, deviate from ideal nutrient consumption profiles and have varying levels of stress and recovery time, depending on deployment type.

Keywords

Wildland firefighting, fatigue, heart rate variability, indirect calorimetry, maximum heart rate, VO_{2max}, activity intensity, energy expenditure, energy intake, stress, recovery, energy balance, nutritional quality, dietary assessment

Co-Authorship Statement

Chapters two and three are presented as a published article and manuscript for publication respectively.

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Author Contributions

Ayden Robertson assisted with data and statistical analysis and interpretation, as well as drafting and editing the manuscript.

Ken King assisted with participant recruitment and data collection, as well as review of the manuscript.

Dr. Stephen Ritchie assisted with conceptualization and design of the study, interpretation of the results, and review of the manuscript.

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Michelle Laurence assisted with participant recruitment and data collection, as well as review of the manuscript.

Dr. Sandra Dorman conceptualized the design of the study, and assisted with interpretation of the results, and review of the manuscript.

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Ayden Robertson assisted with conceptualization and design of the study, participant recruitment, data collection, statistical analysis and interpretation, and drafting and review of the manuscript.

Dr. Céline Larivière assisted with conceptualization and design of the study, interpretation of the results, and review of the manuscript.

Caleb Leduc, assisted with participant recruitment and data collection.

Zachary McGillis assisted with participant recruitment and data collection.

Dr. Tammy Eger assisted with conceptualization and design of the study, interpretation of the results, and review of the manuscript.

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Dr. Michel Larivière assisted with review of the manuscript.

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Acronyms

B: Fire base deployment

bpm: Beats per minute

DLW: Doubly-labelled water

EB: Energy balance (kcal/day)

EE: Energy expenditure (kcal)

EE_{1hr}: Average hourly energy expenditure (kcal/hour)

EE_{peak}: Peak energy expenditure (kcal/minute)

EI: Energy intake (kcal/day)

HR_{max}: Maximum heart rate (beats per minute)

HRV: Heart rate variability (R-R interval) (milliseconds)

IA: Initial attack deployment

IC: Indirect calorimetry

kcal: Kilocalories

MET: Metabolic equivalent (kcal/kg/hour)

ms: milliseconds

P: Project fire deployment

VO_{2max}: Maximum oxygen consumption (ml/kg/min)

Preface

Wildland forest fires affect large, inhabited and uninhabited areas across Canada each year and FireRangers operating out of the Aviation, Forest Fire and Emergency Services (AFFES) Division of the Ministry of Natural Resources and Forestry (MNRF) are tasked with frontline fire suppression duties. FireRangers are required to exercise their duties in unfamiliar and unforgiving outdoor environments and are therefore exposed to a variety of environmental hazards that pose risks for injury, including: unstable, rough terrain; unpredictable weather and fire behaviour; smoke; and heat. Within these conditions it is understandable that FireRangers have exhibited the highest annual injury rates among AFFES positions. Although environmental hazards are evident, FireRangers identify 'fatigue' as an important contributing factor in injury reports. Fatigue generally refers to 'extreme tiredness'; however, causes of fatigue are multifactorial and can lead to reduction in physical and/or mental performance as a result of prolonged physical exertion, sleep loss, lack of recovery, stress and anxiety, and inadequate nutrition, or any combination of each or all. Previous research has shown that wildland fire fighters, outside of Canada, exhibit high daily energy expenditure (~4500kcal/day) coupled with inadequate energy intake to match the energy demands; this is an important consideration given that it is a modifiable contributor to fatigue during fire deployment and it is these components of fatigue that we will examine in this thesis.

Traditional free-living energy expenditure measurement, through the use of doubly-labelled water (DLW), lacks the ability to characterize activity-specific energy demands and the distribution of daily energy expenditure[7]. Analysis of heart rate variability (HRV) however presents as a viable option for measuring daily energy expenditure, characterizing energy demands and physiological reactions (stress, recovery) for specific time periods or activities[31,32], provided that energy expenditure measures are comparable to gold standard measures. In order to justify the use of HRV-monitoring for free-living data collection, validation in comparison to gold standard measures is required.

Therefore, the purpose of this research was, to first validate the use of HRV-based energy expenditure estimation relative to the gold standard of indirect calorimetry, and then to describe modifiable, physiological components of fatigue in Ontario FireRangers by: i) quantifying daily energy expenditure and energy intake (i.e. food consumption); ii) qualifying deployment-specific energy demands and physiological responses (i.e. stress and recovery); and iii) assessing the nutritional quality of foods consumed.

To first determine the accuracy of HRV-based energy expenditure measures, 30 healthy individuals performed low- and high-intensity, laboratory testing while simultaneously logging HRV and indirect calorimetry (IC) data. Correlation of HRV-based EE estimates in both laboratory conditions with IC measures was moderate to strong, and no significant difference was noted between the measures. Furthermore, daily EE estimates during free-living HRV data collection correlated highly across all levels of device calibration (See Chapter 2 and Appendix A). The results of this study therefore support the use of HRV monitoring for the purpose of energy expenditure measurement.

During the 2014 fire season, 21 FireRangers operating out of a northern Ontario Fire Management Headquarters participated in this research and collected data. Participating FireRangers independently collected data using several portable, data collection devices. Zephyr Bioharness3 units were used to collect heart rate variability (HRV) data; which was analysed using FirstBeat SPORT software for estimates of energy expenditure[31,61] and for contextualization of physiological reactions to free-living activity in terms of: physical activity, stress, and recovery[32]. Energy intake and nutritional quality data were collected using the audio-video application on iPod touch© devices (Apple Canada), which created daily food logs. Consumed foods were entered into and analyzed with NutriBase Pro11 software. The audio-video method is a novel adaptation of the photographic dietary assessment developed by Dorman and Gauthier[28,33] that avoids the limitations of traditional self-report methods[40]. Lastly, ActiSleep monitors were used to assist with the estimate of daily energy expenditure, (i.e. worn at night, when HRV monitors were removed).

The results of HRV data analysis showed that FireRangers exhibited high-energy demands during fire deployments (>4000kcal/day) with differences in peak energy demands between: initial attack (IA) deployments (high intensity); and project fire (P) deployments (moderate intensity). Furthermore, FireRangers were found to exhibit low energy intake relative to energy expenditure indicating that they may operate in states of negative energy balance. In addition to low energy intake, FireRangers were observed to consume diets that deviate from macronutrient and micronutrient recommendations[3,36,37] increasing their risk of negative performance outcomes[3,41,55]. Physiologically, FireRangers were found to exhibit higher sympathetic nervous activity and stress reactions during Initial Attack fire deployment, relative to time spent performing deployment-preparatory activities at the Fire Management Headquarters (FMH), Conversely, FireRangers exhibited higher parasympathetic nervous activity and recovery during project fires and shifts at the Fire Management Headquarters, relative to Initial Attack deployments. Taken together, FireRangers were observed to simultaneously exhibit a variety of behaviours and physiological responses within their working conditions that are known to contribute to the development of fatigue (See Chapter 3).

The results of this thesis indicate that HRV monitoring is a valid and practical method with which to collect free-living energy expenditure measurements. Through inclusion of this method alongside the novel method of audio-visual food journaling, we concluded that these two, modifiable factors, known to contribute to the development of fatigue, may place these workers at greater risk of workplace injury. Therefore we recommend that FireRangers adopt fitness and nutritional practices, mirroring those of professional athletes, to promote performance, enhance recovery and prevent injury.

Chapter 1

1.1 Introduction – Forest Fire Suppression in Canada

1.1a History

The Canadian Government has long accepted that forest fires are inevitable, and hence, since 1849 has been involved in the management and prevention of forest fires[49]. The role of the FireRanger was established in 1885, and initially involved putting out fires that were encountered when on patrol in large forested areas while also informing those in the area of the dangers surrounding forest fires[49]. Improved technology and understanding of fire behaviour and weather systems have allowed for refinement of the practice of fighting forest fires, and today involves highly coordinated, multi-team efforts[49,50]. The protection of forests as well as their surrounding rural communities is an important job involving a large scope of demanding duties that are taken seriously by those in the profession.

Front line forest fire suppression involves a coordinated team effort. Fire crews are deployed according to directions from their operational headquarters and are under the direction of the fire operations supervisor. Within each fire crew there is a crew leader who adopts the responsibilities of initial fire investigation and action recommendations, documenting information about the fire, and coordinating the efforts of crew members on deployment while also fulfilling required fire suppression duties[51]. Crew members, under direction of the crew leader, are responsible for equipment setup and maintenance, and using said equipment to perform both initial and sustained fire suppression activities[52]. The number of fire crews deployed for fire suppression depends on the severity of the fire, and each crew consists of a crew leader and 3 crew members.

1.1b FireRangers and Injuries

Despite the advancements in technology and improvements in fire-suppression strategies, the practice of fighting forest fires remains inherently hazardous posing multiple risks to those involved[8,9,18,20,44]. Modern day FireRangers are required to undergo extensive training and meet strict fitness standards in order to be eligible to perform the physically-demanding duties required and function as part of a cohesive unit, over extended deployments; much like military personnel. They are responsible for both initiating and sustaining fire suppression operations, and aside from their role on the fire line, FireRangers must also perform numerous other duties including equipment transport and maintenance to ensure safe and effective fire suppression[5].

Fire suppression occurs in high-risk environments where exposure to erratic fire behaviour, falling trees, unstable ground/footing, smoke, heavy equipment and sharp tools, pose significant threats to worker safety[57]. Slips/trips/falls and use of equipment/tools/machinery are the most common mechanisms of injury (MOI) within this occupation[12,13,14,15,18]. This is understandable given the rough terrain, heavy use of equipment and intense physical activity requirements. Shaw and collaborators[65] state that falls produce higher medical and disability costs in the working population, presumably due to greater injury severity. This is supported by the fact that the injuries experienced by AFFES employees often require time away from work[12,13,14,15]. Due to the physical nature of forest fire suppression, the Lost Time Injury (LTI) rate is higher for this population than the general workforce in Ontario[56], and FireRangers accounted for the majority of WSIB injury claims reported by AFFES employees[12,13,14,15].

Unfortunately, this trend has remained relatively unchanged over the past decade[12,13,14,15] indicating the importance of developing novel approaches to reduce injury occurrence in this workforce. First-aid injuries are also common among FireRangers, while performing their work tasks[8,12,13,14,15,18,20,44]. Specifically, FireRangers experience a large variety of medical aid and lost time injuries to all parts of the body, including sprains/strains/spasms, contusions/abrasions/incisions, insect bites/stings and illnesses[12,13,14,15]; which *may* not require them to be absent from work, but would undoubtedly impact their ability to perform optimally and in a safe manner. Given the physical demands required from this occupational group of workers and the risk of harm, determining and understanding factors that contribute to workplace injuries in the forest-fire management sector is a worthwhile effort.

1.1c Work/Rest Guidelines

The successful suppression of forest fires requires full-time operational schedules. The Aviation, Forest Fire and Emergency Services (AFFES) division of the Ontario Ministry of Natural Resources and Forestry (MNRF) currently has specific policies in place to manage the work and rest schedules of FireRangers[6]. FireRangers are required to be prepared for up to an 18-day mobilization, wherein a maximum of 14 days can be spent on fire or emergency assignment and the remaining time is spent travelling to and from the assignment location[6]. Similar assignment lengths have been documented for wildland fire fighters in other parts of the world[44,64], indicating that extended periods of work are commonplace among the wildland firefighting profession and not limited to AFFES FireRangers. Following continuous work periods, the *minimum* length rest-period for FireRangers is set at two days[6]. The minimum two-day rest period before redeployment is also the standard used for wildland firefighters in other areas of the world (i.e. America, Australia)[44,64].

When a forest fire is in progress, FireRangers are safest and most effective when they are working at their peak performance capacity; achieved through good nutrition and fitness, sufficient rest and sufficient recovery from prior activity; both physically and mentally. The 'working time guideline' used in Canada to manage fatigue is based upon the control stages of a fire and the duration of work on the fire line. The current work/rest guidelines acknowledge the importance of monitoring and accommodating for worker fatigue[6], however the adequacy of work/rest guidelines and their effects on fatigue and recovery has yet to be evaluated through research[64].

1.1d Fatigue

Fatigue has frequently been cited as a major concern in the practice of forest fire suppression, and is influenced by both shift-length and individual factors including: physical fitness, recovery time, sleep time and nutritional status[8,12,13,14,15,20,44,58,,64]. Fatigue refers to the issues that arise from excessive working time or ineffectively designed shift patterns. Generally, fatigue is considered to be a decline in mental and/or physical performance that results from prolonged exertion, inadequate recovery time, and sleep loss[21]. Fatigue results in slower reactions, reduced ability to process information, memory lapses, absent-mindedness, decreased awareness, lack of attention, under-estimation of risk, reduced coordination, as well as other negative outcomes[21]. Fatigue has been shown to predict errors and accidents, ill-health and injury, and reduced productivity[21].

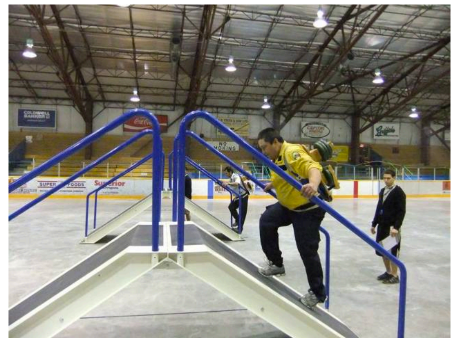
FireRangers are actively engaged in activities that are mentally and physically challenging, and hazardous. During their off-hours, (i.e. at the end of each shift), they return to 'base-camp' located in a fire-safe, yet remote location, often in situations similar to a camping environment. FireRangers are therefore in living conditions very different from their home-life while on the frontline including: limited entertainment, altered sleeping arrangements and limited ability to prepare food. Because they are near ongoing fires, their living conditions can be uncomfortable and include contaminants in their airspace[8,19]. In short, there is an accumulation of mental and physical fatigue, likely contributing to a number of workplace injuries FireRangers experience.

1.1e Occupational Athletes

Athlete: A person who is trained or skilled in exercises, sports, or games requiring physical strength, agility, or stamina[48]. The term "occupational athlete" is one that has been used recently to describe men and women whose jobs require strength, agility, and stamina in a variety of industrial sectors, including fire-fighting[10,43,60]. It suggests that 'keeping fit' and 'being healthy' are the keys to optimal workplace performance; similar to an athlete's training. It is also thought to be fundamental for injury prevention[6]. Injury rates amongst tree-planters have been shown to decline when training programs are implemented aimed at increasing the physical fitness of employees through training protocols that mimic specific job tasks[6]. Thus, as in athletics, there is support for the inclusion of physical training protocols, geared towards improving the fitness of individuals, based on the tasks they will be performing. We hypothesize that a key component of the effectiveness of training in the reduction of injuries is due to a reduction in physical fatigue.

The MNRF first implemented a performance standard for FireRangers in 1997 with the introduction of the Physical Readiness Evaluation for Initial Attack Forest Firefighters (PRE-FIT); because of desires expressed by both management and non-management personnel for efforts to be made to: reduce injury, improve recovery, and increase wellbeing in FireRangers[29]. Today, FireRangers are required to annually complete the WFX-FIT test protocol, implemented in 2012 as a replacement to the PRE-FIT, in order to be certified to work both in Ontario and across Canada[4,23]. This test was developed to determine whether individuals, seeking to become/remain fire rangers, possess the aerobic fitness, muscular strength, and muscular endurance required to fight forest fires[23]. The WFX-FIT is unique, in that it was developed based on the tasks and physical demands performed by FireRangers, meaning that: "the job is the test and the test is the job"[23]. This test is comprised of common FireRanger work activities described further in Table 1. FireRangers may become certified to work solely within Ontario or be eligible for exchange across Canada based on the time it takes them to complete the WFX-FIT test (17:15min & 14:30min respectively)[4,23]. This is a significant improvement from the PRE-FIT, which differed significantly in terms of standards of acceptability across provinces[29], and now provides the MNRF the ability to deploy FireRangers anywhere across Canada based on their WFX-FIT performance[23]. Despite the introduction of these initiatives, injuries among FireRangers still account for the largest proportion of WSIB injury claims filed by AFFES[12,13,14,15]. Given that the fitness standards were established based on the performance of experienced FireRangers, it remains to be seen whether the WFX-FIT is indicative of a level of fitness that is sufficient for FireRangers to manage fatigue and maintain their health and wellbeing over the course of an entire fire season.

Table I. WFX-FIT Test Composition[23]

Description of Test Component	Image of Task
Carry pump on back – simulated pump (28.5kg) carried 160m (4x 40m laps) while traversing a ramp (35 degree pitch, 1.22m height) each lap (8x ramp)	
Hand carry pump – simulated pump (28.5kg) carried 80m (2x 40m laps) without traversing ramp	
Hose pack lift and carry on back – hoist hose pack (25kg) onto back and carry for 1km (25x 40m laps) while traversing a ramp each lap (50x ramp)	
Charged hose advanced – 80m (2x 40m lap) simulated hose advance (18.5kg weighted sled) without traversing ramp	

1.2 Introduction – Components of Fatigue

1.2a Physical Activity

A strong link between the amount of daily work-related physical activity and the development of acute and chronic injuries/disabilities among workers has been reported in the literature[16,27,66,67]. Physical correlates include: intensity of physical demand, age, fitness, history of injury, physical stressors, and recovery[35]. Forest fire suppression is an extremely demanding occupation involving physical activities performed in high temperature and low air quality (i.e. smoke) conditions[8,19], that include hiking, building fire lines, removing brush and setting backfires on steep, uneven terrain[19]; all of which require working with tools that weigh 3-20 kg while wearing heavy personal protective gear (about 6kg)[58,63]. The physiological strain experienced by FireRangers while performing various tasks has been analyzed and research has shown that forest fire suppression involves activities across a range of physical intensities (from moderate to maximal efforts) and duration (short-to-long)[62,75]. Despite the logical hypothesis to the contrary, Vincent and colleagues[74] observed that Australian wildland firefighters are able to maintain task performance, measured using accelerometry, across consecutive shifts regardless of sleep duration. This observation was further substantiated in controlled conditions wherein participating firefighters performed simulated wildfire suppression activities after obtaining normal (8hrs) or restricted sleep (4hrs)[76]. Interestingly, there was also no difference between firefighters' subjective ratings of perceived exertion under normal or restricted sleep conditions, indicating that wildland firefighters are able to adapt in order to maintain performance of wildland fire suppression activities over consecutive shifts[76].

1.2b Energy Expenditure

In order to better understand the physical demands endured by FireRangers throughout a fire season, objective measures of energy expenditure across deployments are required. It has been shown that firefighters experience greater cardio-circulatory strain during fire operations than during medical and performance evaluations meant to determine if individuals are fit for duty[11]. This indicates the importance of tailoring pre-season evaluations to the reality of the work performance. Energy expenditure has also been measured using doubly-labelled water (DLW), the gold standard for free-living (unrestricted activities outside of the laboratory) measures of energy expenditure[7,59], and Ruby and colleagues[63] showed that FireRangers have an average daily expenditure of 4206 ± 717kcal, with 2186 ± 669kcal due to energy expenditure from physical activity. These results indicate that the daily energy expenditure of FireRangers is similar to that experienced by personnel during military operations (4610 ± 650kcal/day)[72]. Although accurate, the DLW method is limited in that it is costly and difficult to administer in the conditions characterizing wildland fire suppression, as well as being unable to provide information in regards to the characteristics (frequency, intensity, time, and type) of the physical activity being performed within a specific time-frame[38,59]. The ability to characterize physical activity is necessary for a comprehensive evaluation of the demands inherent in fire deployments. Research using electronic activity monitors, which are able to characterize physical activity in the ways DLW is unable to, has shown similar results to DLW for average daily energy expenditure (4768 ± 478kcal/day) and energy expenditure from physical activity (2585 ± 406kcal/day) in FireRangers[38,63], indicating that accelerometer and heart rate-based electronic activity monitors can serve as a practical alternative to DLW in environmentally, extreme conditions, and are advantageous in that they allow for data collection over specific and longer periods of time[2,38,59]. As part of a comprehensive evaluation of how FireRangers respond to the physical demands faced over the course of a fire season, the use of an electronic activity monitor is warranted[2,7,59].

While simple heart rate analysis has been found to overestimate energy expenditure[24,30], it is possible to perform a more detailed analysis of heart rate in terms of the variation in beat-to-beat intervals (R-R intervals). Known as heart rate variability (HRV), this measure allows for higher accuracy measures of energy expenditure[54]. Additionally, HRV analysis allows for further contextualization of the data in terms of autonomic nervous system activity[1,2,70]. Based on its ability to provide measures of energy expenditure and simultaneously infer information about individual physiological responses (i.e. stress and recovery) during free-living activity[31,32], HRV monitoring shows potential for use in occupational research, specifically for contextualizing FireRanger energy demands and physiological responses to their working conditions. Allowing for free-living data collection without the need for researcher presence as well as time-specific data analysis are the major strengths of this method over the aforementioned gold standard methods of indirect calorimetry and DLW that, as discussed, are costly and restrictive in nature[2]. HRV monitoring for the purpose of energy expenditure estimation is however not without limitations. In order to most effectively use this method, devices should be calibrated for each individual user using laboratory-based measures[31]. Furthermore, it has been noted that the HRV method produces larger errors (HRV = 7-10% error & IC/DLW = <5% error)[31] and underestimation (~13%) relative to the described gold standard methods[54]. Fortunately, accuracy of these measures has been shown to increase when calibrating the device with laboratory measures[54]. Reliability and validity of the EE estimates produced through HRV monitoring are however also important considerations if selecting their use over proven, gold standard methods.

Montgomery and colleagues[54] showed test-retest reliability of HRV-based EE estimates to be within 5%, indicating acceptable reliability. The observed underestimation relative to gold standard measures is however concerning, and it has therefore been suggested that HRV-based EE monitoring be restricted to the group level [2,54].

1.2c Stress

Stress can have adverse effects on health, both acutely and chronically[32,34]. Increased sympathetic nervous system activity, as measured through HRV monitoring, is indicative of physiological stress reactions[32]. Physiological stress reactions include heightened heart rate, blood pressure, muscle tone, adrenal activity, and energy expenditure[34]. Otherwise known as the fight-or-flight reaction, the aforementioned effects of sympathetic activation are advantageous for immediate protection in dangerous circumstances[47]. However, apart from emergency scenarios, stress reactions via sympathetic activation can also be induced through a variety of other factors in daily life including excess physical workload, environmental stressors, and low control over work activities[32,67]. All of these factors exist in the working environment of FireRangers. Importantly, prolonged or recurrent, sympathetic activation can have a variety of negative health effects. Acutely: prolonged sympathetic arousal can lead to fatigue and incomplete recovery from daily stressors. Chronically: recurrent sympathetic arousal can lead to immune system dysfunction with an increased likelihood of developing infections and eventually contributes to the development of cardiovascular diseases[22,34]. The degree to which FireRangers exhibit physiological stress reactions during varying fire suppression activities has not been examined previously. Current technology with HRV monitoring therefore provides the opportunity to evaluate this component of fatigue.

1.2d Recovery

Parasympathetic nervous activity, as measured through HRV monitoring, is indicative of physiological recovery[32,34]. Parasympathetic activity acts to combat the negative physiological effects of sympathetic activation by reducing heart rate, blood pressure, muscle tone, and promoting energy conservation[34]. Recovery periods are thought to help *prevent* the adverse effects of physically demanding jobs. Less understood is the impact of recovery during non-work periods in mitigating strain and stress. By definition, "recovery: refers to the process during which an individual's functioning returns to its pre-stressor level and in which strain is reduced,"[68]. In other words, recovery refers to restorative activities that may reduce fatigue leading to a state of physiological and psychological "performance readiness"[26]. A worker that is 'well-recovered' is more likely to perform better during a subsequent work period, whereas the performance of a 'poorly-recovered' worker may be sub-optimal with increased risk of job strain and subsequent injury[16,26]. Recovery during work periods, termed internal recovery (i.e. short breaks), is purported to maintain the well-being and job performance of workers[34]. Understanding the circumstances that hamper or promote recovery is an important line of investigation that may help mitigate workplace fatigue and injury[34]. In particular, characterising recovery periods has not been studied in FireRangers. This worker group may be at greater risk of incomplete recovery owing to their demanding work schedule, which is likely to include overtime work. HRV monitoring in-the-field, provides the opportunity to evaluate this component of fatigue.

1.2e Sleep

Sleep deprivation has many causes. For FireRangers who are reporting for duty, sleep deprivation may be the result of a shortened sleep time or decreased sleep quality. Due to job demands, FireRangers are often unable to obtain restorative sleep[8]; sleep is of reduced length, fragmented, and when studied objectively, may indicate reduced sleep efficiency (the ratio of total sleep time to time in bed). This may be due to endogenous biological factors that inhibit the type of sleep normally acquired during a regular night's sleep. As described above, FireRangers sleep in environments that may prevent good quality sleep and contribute to cognitive decline. Prolonged wakefulness without restorative sleep has been shown to result in decreased cognitive performance, similar to that observed under the influence of alcohol[77]. Vincent and colleagues[75] analyzed Australian wildland firefighters' sleep patterns during a fire season and observed that participating firefighters slept less and had higher subjective ratings of fatigue during fire days relative to non-fire days. Furthermore, the results of this study indicated that with an average of 6 hours sleep during fire days, and even less if required to sleep in a tent or a vehicle, wildland firefighters do not obtain an adequate amount of sleep[73].

1.2f Nutrition

Given the high kilocalorie expenditure estimated for FireRangers, the importance of a balanced kilocalorie intake is obvious. Perhaps less obvious is the value of good nutrition in rebuilding and repairing tissues, supporting a healthy immune system and maintaining normal bodily functions[3,41]. Forest fire suppression requires similar energy demands to that of military personnel, yet it has been shown that both of these populations consume less energy than they expend during their intense activities[63,72]. In a previous study, wildland firefighters were found to operate under an energy deficit of ~550kcal/day, resulting in body weight changes even over a short-term deployment (i.e. 5 days)[63]. While assessing glycogen levels in wildland fire fighters, Cuddy and colleagues[25] found that consuming 2195 ± 699kcal during a shift effectively maintained glycogen levels, however they acknowledge that the activity levels of firefighters during the data collection shift was markedly lower than that shown in previous studies, indicating the need for analysis over a longer period, encompassing a wider range of work intensities. Another barrier to sufficient energy intake is the form in which food is provided to wildland firefighters. Montain and colleagues[53] sought to determine whether meal-based (MRE) or snack-based (FSR) food provisions, similar to those provided to military personnel, would be more readily consumed by FireRangers, and if either method showed benefits in terms of work output. They found that FireRangers consumed 83% of FSR as opposed to 78% of MRE, and exhibited higher work output when provided with FSR[53]. This is supported by research by Cuddy et al, who suggest that regular snacking during wildfire suppression increases work output[25]. Interestingly, the food provisions that were supplied to wildland firefighters only contained between 2840-3150kcal total[53], indicating they were being provided with insufficient calories to match the energy demands of their occupation[63]. In the case of FireRangers with the MNRF, who are able to place requests for specific food provisions while on deployment, it is important to evaluate if they consume sufficient energy to match the demands of their work, as well as the manner in which they choose to consume their energy (ie. snack-based or meal-based).

The recommendations by Canada's Dietary Reference Intakes (DRIs), provide information about the required daily intake of macronutrients (carbohydrate, protein, and fat) and micronutrients (vitamins & minerals) in order to maintain good health[36,37]. The Average Macronutrient Distribution Range (AMDR) for carbohydrate, protein and fat, indicate that individuals 19 years and over should consume a diet consisting of 45-65% carbohydrate, 10-35% protein, and 20-35% fat (preferably unsaturated fats with <10% from saturated fats)[36]. Ruby and colleagues[63] found that FireRangers consumed a diet consisting of 52.8 ± 6.9% carbohydrate, 14.4 ± 2.4% protein, and 31.8 ± 6.2% fat during the course of their data collection. Cuddy and colleagues[25] found wildland firefighters consumed 59 ± 6% carbohydrate, 12 ± 3% protein, and 31 ± 7% fat during the 12hr shifts in which they collected data. Both of these studies indicate that wildland firefighter's macronutrient consumption falls within the bounds of the Canadian Food Guide recommendations. However while the AMDRs are acceptable guidelines, individuals may need to increase their overall macronutrient intake in order to meet the energy demands of prolonged activities[3]; these recommendations were not developed specific to athletes. Therefore, it is also suggested that individuals performing endurance- and strength-based activities on consecutive days augment their carbohydrate and protein consumption in order to replenish muscle glycogen and repair tissues[3,17]. The World Health Organization and Health Canada recommend that individuals consume a at least 130g of carbohydrates daily, with no more than 10% coming from simple sugars and with 38g coming from fiber[37,76] however these recommendations do not consider the need to increase the recommendation for athletes training regularly[3]. To account for athletes increased energy demands, the American College of Sports Medicine (ACSM) recommends that athletes consume 6-10g/kg carbohydrates, as well as 1.2-1.7g/kg protein to promote muscle tissue maintenance[3].

Adequate vitamin and mineral consumption are also key to maintaining performance during, and promoting recovery following, regular exercise[3,37]. Micronutrients have important roles in metbolism, oxygen transport, nerve conduction, maintenance of muscle and bone, immune function, and protection from oxidative damage[3]. Because of the increased usage of micronutrients during regular exercise individuals with unbalanced or deficient diets may be at risk for reduced performance, increased fatigue, and poor recovery[3]. Comprehensive analysis of macro/micronutrient consumption and the dietary habits of FireRangers over the entire course of a fire season has never been performed, but will undoubtedly provide important insights into the fatigue and recovery they experience.

1.2g Assessment of Daily Food Consumption

In order to assess energy consumption and nutritional quality, a variety of methods are available for use. Traditionally, dietary analysis has been conducted using self-report and dietary recall methods such as food-frequency questionnaires and 24-hour recall, however several limitations have been noted with these methods including: underestimation, participant inadherence, incomplete data, amd reliance on participant memory[40].

The use of innovative technologies has been emerging in the literature as research groups try to improve dietary assessment in various settings. Mobile phone, scan and sensor-based technologies have improved real-time recording at eating events, but are generally thought to mainly enhance current dietary assessment tools (food-frequency surveys, diary), so that the data collection and analysis is less laborious, rather than implementing truly novel approaches[40].

The most novel approach to assessing food today has been the implementation of digital photography to capture food intake. This method was developed to unobtrusively capture food intake and subsequently eliminate the need for self-reports[45]. Advantages of this method include its low cost, limited participant burden, rapid data collection, and the possibility to extend the method to collect data on populations[46]. Several groups have experimented with photography to determine its reliability for food assessment and are outlined below.

Williamson and colleagues[78] were the first to compare digital photography and visual estimation of portion size, and then compared both of these methods to weighed measures of food in university cafeterias. Sixty meals with ten different portion sizes were prepared and weighed. They found high correlations between portion sizes, for food selections, plate waste and food intake between both methods. They also found that both methods tended to yield small over- or under-estimates of weighed food. They concluded that digital photography would be useful for measuring food intake in settings that allow for the direct observation of food selections and plate waste. They also concluded that minimal disruption of the eating environment was important and might be better achieved with photography and that the photos allowed for unhurried estimates of portion size.

Other researchers have also measured the reliability and validity of digital photography in assessing children's food. Martin and colleagues[45] examined intake and the effects of second servings upon food intake in a school cafeteria. They reported the method to be reliable, but also demonstrated the utility of photography for studies of food intake and body weight. Swanson and colleagues[69] studied children's lunch trays, photographing them before and after eating periods; they concluded that the method was cost-effective, unobtrusive, accurate and reliable for measuring food consumption in a school setting for both comprehensive nutritional analysis or for simple counts of servings of food groups.

Higgins and colleagues[39] also performed a validation study comparing 3 days of meals assessed using a weighed diet and compared to digital photography in adolescents. There was no difference between the diet diary and photographic estimates of total energy, carbohydrate, fat, protein, fiber, vitamins A, D and E, calcium, iron or zinc compared to actual intake. However, both participants and their parents reported that the photographic method was quicker, simpler and would be preferred if they were to record dietary intake in the future. In this study cohort, 36% of subjects accurately reported actual daily energy intake (±5% of actual intake), 29% under-reported energy intake and 35% over-reported energy intake.

Dorman and Gauthier performed research which supports the use of a dietary assessment methodology based on photographic food logging and subsequent analysis in nutritional analysis software such (i.e. NutriBase) allowing for brand specific analysis and production of detailed macronutrient and micronutrient reports to evaluate if nutritional needs are being met and if specific nutritional deficiencies exist[28,33].

The only study to date, to the author's knowledge, that reported negative findings for the use of photography was Kikunaga and colleagues[42]. This group used a handheld personal digital assistant with camera and mobile phone card. They concluded that this device required better resolution to adequately assess the photographs; however, the photographic method they used, was preferred by participants over the weighted diet record.

Taken together the literature supports the use of digital photography, providing the picture resolution is of good quality. Under scenarios where the entire meal can be seen, photographs were found to be just as good as visual estimations. However, in cases where visual estimation was insufficient to determine food choices, food diary data is still required. Importantly all groups reported that the method was well tolerated and in fact, preferred by participants. Based on the support for photography-based dietary assessment, the method shows potential for adaptation and use in in occupational settings.

1.3 Field Study

1.3a Purpose

Consistently high, annual, injury rates in FireRangers, cited to be attributable to physical and mental fatigue, are a concern for the MNRF[12,13,14,15]. Working conditions requiring prolonged physical exertion without adequate opportunity to recover are related to the development of both acute and chronic injury and health concerns[16,27,66,67]. Daily energy expenditure is a useful measure for the relative physical intensity of workplace activities. Having had its accuracy validated against a gold standard measure (indirect calorimetry), there is support for the use of HRV-based energy expenditure (EE) measurement[54]. Compared to the gold-standard free-living measure of energy expenditure, doubly-labelled water (DLW), HRV analysis has the added advantage of being able to contextualize activity-specific energy demands over the data log period[31]. Previous research has however been isolated to evaluation of HRV-based EE accuracy in young, high-level athletes[54]. It is therefore also important to evaluate HRV-based EE accuracy in healthy individuals who are not training as high-level athletes in order to broaden the scope in which this method is applicable.

FireRangers' working conditions are such that they are inherently conducive to the development of fatigue via high-energy demands, prolonged stress reactions, and a potential lack-of-opportunities for recovery. Given the unpredictable nature of fire deployments, which may range from low- to high-intensity, FireRangers must be able to adapt accordingly to the demands of their working environment through physical preparedness and appropriate nutritional practices. The literature indicates that wildland fire fighters in other parts of the world exhibit high energy expenditure and do not consume adequate food energy to match energy demands[38,53,63]. These findings, as well as the injury trends observed in Ontario FireRangers, highlight the importance of assessing the magnitude to which modifiable factors are exhibited by FireRangers; specific to the context of the Canadian wildland fire-fighting environment.

Therefore, the purpose of this thesis was to first, evaluate the accuracy of HRV-based energy expenditure measures relative to those obtained via the gold standard of indirect calorimetry; and then to describe modifiable, physiological components of fatigue in FireRangers by: i) quantifying daily energy expenditure and energy intake (i.e. food consumption); ii) qualifying deployment-specific energy demands and physiological responses (i.e. stress and recovery); iii) assessing the nutritional quality of foods consumed; and iv) measuring the quantity.

1.3b Hypotheses

1. HRV-based EE estimates will correlate strongly with those obtained using Indirect Calorimetry.

2. FireRangers will exhibit the following fatigue-related factors:

i. During Initial Attack Deployments: high energy expenditure, high physical activity time, more time under stress, less recovery time, inadequate energy intake, and poor nutritional quality.

ii. During Project Fire Deployments: high energy expenditure, high physical activity time, less time under stress, less recovery time, inadequate energy intake, and poor nutritional quality.

iii. During Base Camp Deployments: low energy expenditure, moderate physical activity time, less time under stress, more recovery time, adequate energy intake, and adequate nutritional quality.

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Chapter 2

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Validating the Use of Heart Rate Variability for Estimating Energy Expenditure

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Abstract The ability to measure free-living and activity-specific energy expenditure (EE) is useful for a variety of purposes. Heart rate variability (HRV) monitoring is emerging as a means for estimating EE and other physiological measures. The purpose of this study was to assess the accuracy of HRV-derived EE across a range of physical intensities and during free-living. Participants (n=30) completed two treadmill tests (walk and VO_{2max}) measuring EE via Indirect Calorimetry (IC) and with the FirstBeat Bodyguard HRV monitor. Participants also wore the HRV monitors continuously for four consecutive days under free-living conditions. During the walk test, HRV-EE estimates across analysis conditions correlated moderately with IC estimates of EE ($r=0.60$-0.75; $p<0.05$). During VO_{2max} testing, HRV-EE estimates across analysis conditions correlated strongly with IC estimates of EE with ($r=0.85$-0.98; $p<0.05$). During free-living conditions, daily average and 4-day total HRV-EE estimates across all analysis conditions correlated strongly ($r=0.75$-0.98; $p<0.05$). HRV-EE estimation improves as activity-intensity increases. HRV-EE estimates improve further with the addition of IC-measured HR_{max} and VO_{2max}, particularly at low intensities; however, meaningful differences were not seen between values when considering group means. HRV-EE estimates are sufficiently accurate to indicate this method possesses practical utility and may be used for individual EE monitoring.

Keywords Heart Rate Variability, Indirect Calorimetry, Maximum Heart Rate, VO_{2max}, Activity Intensity

1. Introduction

The ability to assess an individual's energy expenditure (EE) is useful in a multitude of athletic-, lifestyle-, and health-related scenarios. For athletes performing intense training on a daily basis, EE monitoring can provide valuable information to optimize energy intake and training duration, intensity, and frequency to promote peak performance while avoiding overtraining. Individuals with inactivity-related health issues, or those seeking to improve their health, can also benefit from daily EE monitoring by tracking physical activity patterns and tailoring energy intake accordingly. However, EE monitoring can only be beneficial if the chosen method of measurement is reliable and accurate.

Generally, EE assessment can be accomplished using several different methods of measurement and analysis including: direct (DC) and indirect (IC) calorimetry, doubly labelled water (DLW), heart-rate (HR), accelerometers, activity diaries and most recently, heart-rate variability monitors. DC and IC are considered the most accurate methods of assessment [3, 12, 13], however they require costly laboratory equipment and expertise. Doubly labelled water is the most accurate free-living assessment of EE, however this method is only capable of measuring block-periods of EE (e.g. 48h), does not allow for activity-specific EE analysis and is not readily accessible for use [2, 3]. Accelerometers and activity diaries are the least expensive methods, but their accuracy in field studies has been questioned [3, 9, 11].

The use of HR devices for estimating EE has become mainstream in the last decade, particularly for use in athletes, both professional and amateur. The added advantages of these devices is that they allow for free-living data collection and the determination of activity-specific EE while being more cost-effective than IC, DC and DLW, and more accurate than accelerometers or diary records [9]. This is based upon the linear relationship between heart rate and kilocalorie expenditure at sub-maximal exercise intensity, making HR measurement a good surrogate measure for EE estimation [2, 5, 14]. Adding to the appeal and versatility of HR-based EE estimation is the ability to obtain reasonably accurate EE measurements without the need for individual calibration of the monitoring device. Rennie, et al. [16] compared EE values obtained from HR monitoring of subjects over 4-days and found that the values obtained with and without individual device calibration were highly correlated. The ability to obtain accurate EE measures without the need for device calibration, beyond inputting basic personal informtion (age, height, weight, activity level), is appealing because the testing necessary to obtain the measures for full device calibration (i.e. maximal HR (HR_{max}) and maximal oxygen consumpation (VO_{2max})) requires an individual to exercise at high intensity and may be contra-indicated for individuals with existing health concerns.

To date, studies have shown over-estimation of EE using traditional HR methods in comparison to gold-standard measures [5, 7]. To address this, FirstBeat Technologies Ltd. [8] (among others) developed a Heart Rate Variability (HRV) monitor and analysis software. This device acts like an electrocardiogram, continuously recording the variation of beat-to-beat intervals, also known as R-R intervals. The FirstBeat Software developed for use with this device then utilizes the HRV data, as well as information about respiration rate and On/Off response kinetics of VO_2 derived from R-R-interval, to estimate EE [8]. This is more accurate than HR estimation alone [14].

HRV measurement has the additional benefit of being able to provide information regarding parasympathetic and sympathetic nervous system input on HR, and it can be used to extrapolate information regarding disease risk, stress, recovery, activity intensity, training effect, and energy expenditure [1, 2, 8, 18]. These applications hold promise for extended use of these devices, (i.e. outside of sport) in free-living conditions; specifically for more health-related monitoring.

Montgomery et al. [14] first investigated the accuracy of the HRV system, using data obtained from a Suunto HR device analyzed in Firstbeat Technologies software, to estimate EE compared to IC during sub-maximal and maximal intensity exercise on a treadmill. Their study showed improvement of EE estimation across the three levels of analysis at moderate to high intensities compared to HR estimations, however all analyses showed an underestimation of the EE compared to IC. They argued that accuracy is primarily lost at maximal intensities and that inputting measured maximal HR and VO_{2max} significantly improved accuracy. This particular study however focused solely on trained athletes and only evaluated EE derived from the HRV data against IC at moderate-to-high intensity activity.

To date, investigation of HRV-based EE estimation in comparison to IC during low intensity activity and daily living in non-athlete participants has never been done. Considering the potential applications of the FirstBeat Bodyguard, the accuracy and performance of the device across a full range of physical intensities needs to be studied in order to validate its accuracy and in turn its use as a practical tool for estimation of EE in a variety of settings and contexts.

For the benefits of EE monitoring to be applied within the general population for the purposes of exercise prescription, health maintenance, physical capacity assessment, and activity monitoring, it is crucial that the device used be: user-friendly, mobile, and comfortable under every-day living conditions. Additionally, it should be capable of individual-calibration, based on estimates, without the need for gold standard laboratory measures, specifically for VO_{2max}, or HR_{max}, while still providing accurate EE measurements. An important consideration for the expanded use of this technology is whether or not it is necessary to obtain measured maximum/minimum Heart Rate (HR) and maximum oxygen consumption (VO_{2max}) values in order to individually calibrate the device and software for EE calculation. These two measures require the subject to exercise at increasing intensities (often on a treadmill) until exhaustion. Due to these requirements they maintain an inherent level of risk, specifically for a heart attack, and therefore are only performed in clinical or laboratory settings. Even under these conditions, some people would be excluded from performing these tests as a precaution. However, using less invasive means, we can estimate an individual's HR_{max} and VO_{2max}. EE has been found to be reasonably estimated without individual calibration of HR monitoring devices [16], however it has yet to be determined if individual calibration using measured HR_{max} and VO_{2max} is a necessity for accurate EE measurement using the Firstbeat Bodyguard HRV device and analysis software. EE monitoring during physical activity and daily-living, in conjunction with dietary caloric restriction, is a useful tool for achieving weight loss and long-term maintenance of a healthy weight [6] but it is important to ensure that a device chosen for this and related purposes does not provide inaccurate EE estimates.

Therefore, the purpose of this study is threefold: i) to compare the EE estimates of the FirstBeat HRV monitor during low intensity exercise (i.e. 30 minute walking) with EE measured using Indirect Calorimetry; ii) to compare the EE estimates of the FirstBeat HRV monitor during maximum intensity exercise (i.e. VO_{2max} test) with EE measured using Indirect Calorimetry; and iii) to compare EE estimates under conditions of daily living, as calculated using measured (with Indirect Calorimetry) versus estimated (standard estimates and FirstBeat measured estimates) of HR_{max} and VO_{2max}.

2. Materials and Methods

Participants

Thirty adult participants consented to be involved in this study. All were healthy, non-smoking and non-elite athletes. Participants were screened using the PAR-Q [4] and a general Health Status form to assess their capacity to safely perform a VO_{2max} test. If any contraindications were identified on either form, the participant was excluded from the study; however no one was excluded for this reason. During laboratory testing and analysis, 6 participants were removed from the study due to missing HRV data during the low intensity and/or maximum intensity treadmill testing, resulting in a total of 24 participants (12 females, 12 males). Missing data resulted from detachment of the electrode due to excess sweat as well as from loss of connection between the electrode cables and the HRV data logger.

Upon completion of the laboratory testing, the participants continued wearing the HRV monitors for an additional four days of data collection. Seventeen participants (10 females, 7 males) returned the devices with four full days of data that were available for analysis. The other 13 participants either had large gaps in their HRV data due to periodic device removal, or they did not return the devices with four full days of data; therefore they were not included in the free-living data analysis. This study received approval from the Laurentian University Research Ethics Board and all participants provided written consent prior to commencing the study.

Laboratory Study Design

Participants visited the laboratory once for approximately 90-minutes. Preliminary test measures were taken: age, height, weight, and resting heart rate (HR_{rest}). After this, each participant completed two consecutive treadmill-based tests, separated by a 2-minute break: 1) a 30-minute, low intensity walk test; and 2) a high intensity, maximal oxygen consumption (VO_{2max}) test. Participants wore the FirstBeat Bodyguard heart rate variability (HRV) monitors, as per manufacturer instructions, throughout testing as well as having their oxygen consumption continuously measured using a SensorMedics Vmax-29c metabolic cart.

Maximum heart rate (HR_{max} = beats per minute) was calculated by two methods: i) estimated HR_{max} using Tanaka et al. [17] (208-(0.7*age = HR_{maxP}); and ii) measured HR_{max} via the FirstBeat Bodyguard 2 during the high intensity test (HR_{maxM}).

Maximal oxygen consumption (VO_{2max} = ml/kg/min) was calculated through two methods: i) estimation using fitness activity classifications (0-10) as described in the FB Sport Software program (VO_{2maxFB}); and ii) measured using the SensorMedics Vmax-29c metabolic card during the high intensity test ($V0_{2maxIC}$).

Using various combinations of these measures, EE values were compared across four conditions: i) obtained from IC measures (EE_{IC}) - walk test and high intensity tests only; ii) obtained from the FirstBeat SPORT (FB) software using estimated HR_{max} and activity class (EE_1); iii) obtained from the FB software using measured HR_{max} and VO_{2maxFB} (EE_2); and iv) obtained from the FB software using measured HR_{max}, and VO_{2maxIC} (EE_3). Table I summarizes the four different comparison conditions of measuring or estimating EE.

Table I. Comparison conditions for measuring and estimating EE

Variable	Description
EE_{IC}	Output from indirect calorimetry
EE_1	FB software w/ age-predicted HR_{max} and activity level (0-10)
EE_2	FB software w/ measured HR_{max} and VO_{2maxFB}
EE_3	FB software w/ measured HR_{max} and VO_{2maxIC}

30-minute Low-intensity Test

The participants walked at a speed that was set such that it would elicit a heart rate of between 20-39% of the participant's heart rate reserve (Target HR = %*(HR_{max}-HR_{rest})+HR_{rest}), which is indicative of a light-intensity exercise [15]. This information was established for each individual participant in advance of the testing and monitored for the duration of the testing by a member of the research team through the use of a Polar FT7 HR monitor. Following the low-intensity treadmill test, the participant was given a two-minute break prior to commencing a VO_{2max} test.

VO_{2max} Test

As described in the Physiology of Exercise (1984) and outlined here**,** the participant started with a 5-minute warm-up at a moderate walking speed with no gradient. The test was performed in stages of 2-minutes, with speed and/or gradient increasing at the beginning of each successive stage. Each 2-minute stage length provided sufficient time to attain steady-state values. The increases in speed and gradient at each stage ranged from 0-1.5 mph and 0-10% respectively. HR was recorded throughout the procedure using the Polar FT7 HR monitor as a safety precaution, to ensure heart rate remained below each participant's estimated maximum heart rate as previously indicated. The test continued until VO_2 consumption plateaued with increasing exercise intensity indicating the limit at which no further increase in oxygen consumption can occur [10]. Once the exercise test was voluntarily terminated due to exhaustion, the speed and gradient on the treadmill was reduced to a walking speed with no gradient, for a five-minute cool-down period. Multiple members of the research team were present throughout the test to ensure the safety of the participants.

Daily Free-living

Participants that wore the HRV device for the extended data-logging period did so commencing after the laboratory session. The devices were worn continuously, except when removed for hygiene purposes and to replace electrodes. Following four consecutive days of wear, participants returned the devices to a member of the research team.

Data Analysis

Data collected from the FirstBeat HRV monitors was imported into the FirstBeat SPORT computer software program for analysis. EE expenditure was calculated in four ways for the low and high intensity tests: i) EE_{IC} (the gold standard), EE_1, EE_2 and EE_3. During the 4-day wear period of Active Living Conditions, EE expenditure, was calculated in three ways: EE_1, EE_2 and EE_3

All data was recorded as the mean plus/minus the standard error of the mean (SEM). The EE data from the metabolic cart (EE_{IC}) was compared to EE calculated using data from the Firstbeat Bodyguard 2 HRV devices analysed in the Firstbeat SPORT software under the aforementioned conditions: $EE_{1,}$ EE_2, & EE_3. Bland Altman plots, created using SigmaPlot 13, indicated that the variance in the measures across all software analysis conditions tst was within a reasonable range (±2SD) for further statistical analysis (Figures not shown). Paired t-tests, intraclass correlations, and descriptive statistics were used to detect meaningful differences and consistency between the measures. The EE data for each day of the 4-day free-living period was calculated using the Firstbeat SPORT software under the same conditions (EE_1, EE_2, & EE_3) and compared collectively (17 participants x 4 complete days of data = 68 individual days of data). All statistical tests were performed using SPSS version 20.0 and significance was accepted at $p<0.05$.

3. Results

Average age, height, and weight (±SD) of the 24 participants with intact data for the laboratory tests were: 22±2.3 years, 174±8.9cm, and 71±10.2kg respectively.

HR_{max} measured and predicted; and VO_{2max} values measured from FB and IC correlated modestly, but significantly (see Table II).

Table 2. Average measured (IC) and predicted (FB) values of participant laboratory testing (n=24) using basic information for HR_{max} and VO_{2max}

HR_{maxP} bpm ± SD	HR_{maxM} bpm ± SD	Mean difference (bpm)	%diff	SEM	r	p
193 ±1.6	189±10.0	4.08	2.1%	1.93	0.441	0.031

VO_{2maxFB} $ml^{-1}kg^{-1}min$±SD	VO_{2maxIC} $ml^{-1}kg^{-1}min$ ± SD	Mean difference ($ml^{-1}kg^{-1}min$)	%diff	SEM	r	p
46.7±6.4	46.1±7.6	0.61	1.3%	1.45	0.493	0.014

HR_{maxP} = estimated maximal heart rate using age-based equation
HR_{maxM} = measured maximal heart rate during the VO_{2max} test
VO_{2maxFB} = maximal oxygen consumption estimated by FirstBeat SPORT software during the VO_{2max} test
VO_{2maxIC} = maximal oxygen consumption measured by Indirect Calorimetry during the VO_{2max} test
bpm = beats per minute

Low-intensity Walk Test

During the 30 minute low-intensity test, average EE values (±SE) were: EE_{IC}: 168±11.4 kcal; EE_1: 167±10.3 kcal; EE_2: 161±9.4 kcal; and EE_3: 158±8.9 kcal. Paired t-tests indicated no significant differences between EE_{IC} and any of the FB analysis conditions.

EE_{IC} correlated significantly ($p<0.05$) with all FB analysis conditions (see Figure 1). When comparing correlations amongst the three FB analysis conditions, EE_{IC} correlated most closely with EE_3 (see Figure 1).

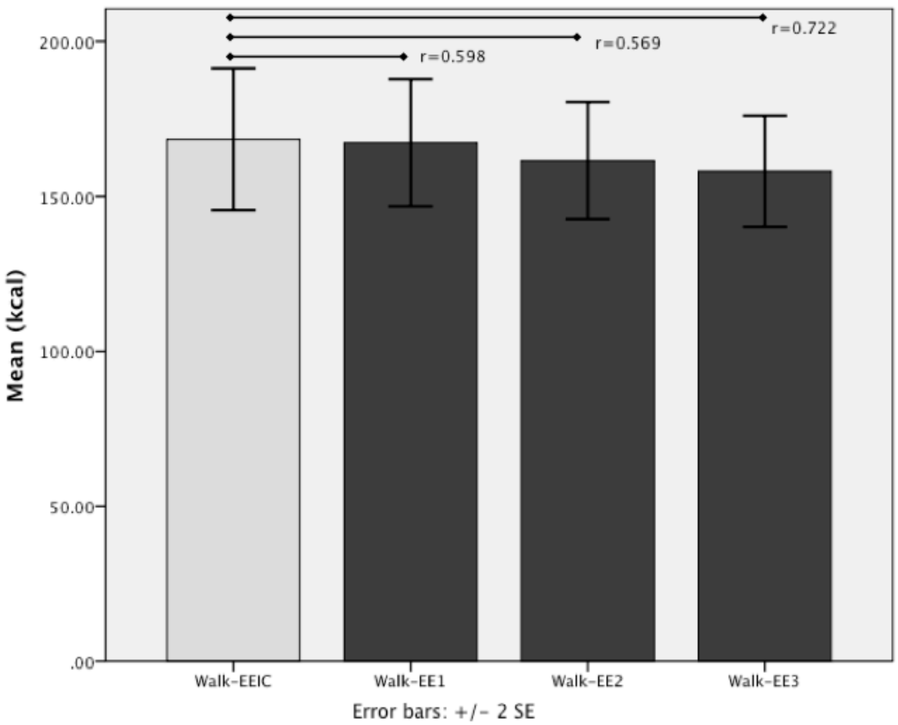

Figure 1. Average Kilocalorie expenditures during the low-intensity walk test as estimated by EEIC, EE1, EE2, and EE3

Maximum Intensity VO_{2max} Test

In the maximum intensity VO_{2max} test, average EE values (±SE) were: EE_{IC}: 168±14.2 kcal; EE_1: 178±14.7 kcal; EE_2: 170±13.8 kcal; and EE_3: 168±13.7 kcal. Paired t-tests indicated no significant differences between EE_{IC} and any of the FB analysis conditions.

EE_{IC} correlated significantly ($p<0.05$) with all FB analysis conditions (see Figure 2). When comparing correlations amongst the three FB analysis conditions EE_{IC} correlated most closely with EE_3 (see Figure 2).

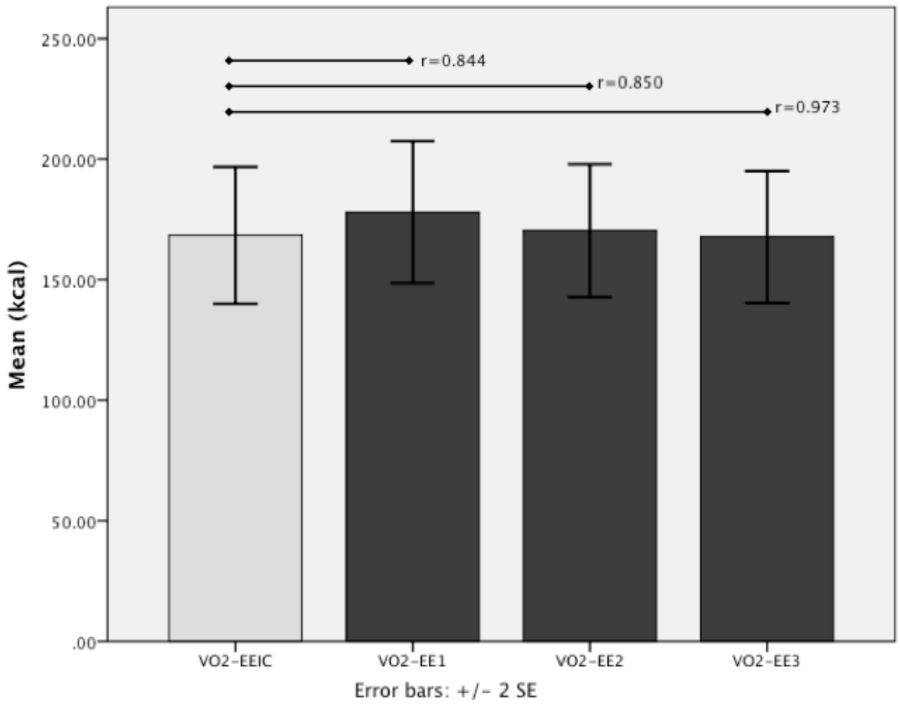

Figure 2. Average Kilocalorie expenditures during the maximum intensity VO_{2max} test as estimated by EEIC, EE1, EE2 and EE3.

Daily Free-living Energy Expenditure

Average age, height, and weight of the participants with 4 full days of data (n=17, 68 total days) were: 22±2.6 years, 172±9.3 cm, and 68±9.5 kg respectively.

Measured and predicted HR_{max} correlated weakly; and VO_{2max} values measured from FB and IC correlated moderately (see Table III).

Table 3. Average measured (IC) and predicted (FB) values of participant free-living (n=17) using basic information for HR_{max} and VO_{2max}

HR_{maxP} bpm±SD	HR_{maxM} Bpm ± SD	Mean difference (bpm)	%diff	SEM	r	p
193 ±1.8	189±9.0	4.65	2.4%	2.05	0.396	0.115

VO_{2maxFB} $ml^{-1}kg^{-1}min$±SD	VO_{2maxIC} $ml^{-1}kg^{-1}min$ ± SD	Mean difference ($ml^{-1}kg^{-1}min$)	%diff	SEM	r	p
46.1±6.3	45.5±8.1	0.59	1.3%	1.75	0.514	0.035

During the four-day data collection period, average values for the individual sample days (±SE) (n=68) were: EE_1: 2681±80.04kcal; EE_2: 2626±73.57 kcal; and EE_3: 2568±68.45 kcal. Paired t-tests indicated significant differences between EE_1 & EE_2 (p=0.001), and between E_1 & EE_3 (p=0.011). EE_1 correlated significantly with EE_2 (r=0.983; p<0.0001) and EE_3 (r=0.844; p<0.0001).

Four-day total values (±SE) (n=17) were: EE_1: 10,724±544.1 kcal; EE_2: 10,506±491.2 kcal; and EE_3: 10,273±451.7 kcal. Paired t-tests indicated no significant differences between EE_1 & EE_2 (p=0.061), nor between EE_1 and EE_3 (p=0.198). EE_1 correlated significantly with EE_2 (r=0.983 p<0.0001) and EE_3 (r=0.788; p<0.0001).

4. Discussion

The information that can be extrapolated from HRV monitoring is appealing for a variety of both clinical and athletic purposes. Therefore various groups including hospitals, sports teams, and researchers have begun implementing these devices for various causes, including energy expenditure monitoring.

Implementation within the general population has occurred with the elimination of laboratory measures of VO_{2max} and HR_{max}. Montgomery et al. [14] showed that these values are important in order to obtain accurate estimates, although this study was in a small population of elite athletes and during high intensity testing. In order to advocate for the use of HRV-based EE estimations outside of these limited circumstances, it is important to further examine its capabilities under more varied conditions and in non-elite athletes to better understand the accuracy of its outputs.

The FirstBeat SPORT software is capable of analyzing HRV data to obtain EE values using various levels of subject baseline information, each increasing in the level of information detail, which informed the decisions surrounding the particular levels of analysis that were chosen for comparison in this study. EE_1 is the most basic level of analysis capable by the FirstBeat SPORT software and uses subject age, height, weight, HR_{rest}, HR_{maxP}, and activity level (0-10) to estimate VO_{2max} via the software's energy expenditure algorithm (VO_{2maxFB}). This level of analysis would be utilized in the event an individual is deemed physically unable to perform the testing required or does not have access to the equipment and personnel to obtain HR_{max} and VO_{2max} values. Thus, this level of analysis is of particular interest since it does not require any testing to be performed for individual device calibration; if, the EE estimates are sufficiently accurate in comparison to IC. EE_2 was the next level of analysis chosen for comparison to IC and substitutes HR_{maxP} with HR_{maxM}, as well as substitutes activity level with VO_{2maxFB}. EE_2 was selected based on the scenario wherein an individual is deemed capable of performing maximal exertion activity, but does not have access to the equipment required to obtain VO_{2max} from gold standard methods of measurement (i.e. indirect calorimetry). In this analysis condition, individual device calibration would be completed by the subject performing a maximum intensity test while wearing the device and obtaining VO_{2maxFB} from a preliminary analysis of the HRV data (i.e. EE_1). EE_3 was the final level of analysis selected for comparison to IC and substitutes VO_{2maxIC} for VO_{2maxFB}. This level of analysis uses participant information obtained from gold standard measures, and is therefore that which most closely replicates the IC analysis conditions using the FirstBeat SPORT software.

To determine whether EE derived from the various levels of HRV analysis is accurate compared to Indirect Calorimetry, intra-class correlations and bland-altman plots, paired t-tests, and descriptive statistics (mean and percentage differences) were used to look for meaningful differences and consistency between the methods of measurement. Correlation coefficients were interpreted as follows: $r<0.35$=low/weak correlation; $0.36<r<0.67$ moderate correlation; $0.68<r\leq 1.0$=high/strong correlation [19].

A key purpose of this study was to establish whether or not it is necessary to obtain HR_{max} and VO_{2max} baseline measures prior to the use of HRV devices to monitor individuals during free-living activity. This was necessary and important to determine since testing to obtain these values is invasive, costly and cannot be conducted in many at-risk populations. A moderate, but significant, correlation was found between measured and predicted HR_{max} and VO_{2max} ($r=0.441$; $p<0.05$ and $r=0.493$; $p<0.05$ respectively), and significant difference was found between measured and predicted HR_{max} ($p=0.045$), but not between estimates of VO_{2max} ($p=0.680$), using paired t-tests. Interestingly, the difference in means between measured and predicted HR_{max} and VO_{2max} values (2.1% and 1.3% respectively) was minimal, indicating that estimation accuracy improves when considering groups of subjects. While the FirstBeat software does not predict HR_{max} and VO_{2max} accurately enough on an individual level to justify substituting HRV-based estimations of these values for those from IC; estimation of HR_{max} and VO_{2max} improves in relation to gold standard values at the group level.

In this study, we compared the use of HRV devices for energy expenditure estimation under three conditions: a low intensity walk test, a maximum intensity VO_{2max} test, and during extended conditions of daily free-living.

During low-intensity activity, underestimation of EE and moderately strong intra-class correlations were found using the FirstBeat software HRV analysis in comparison to gas-exchange EE estimations (see Figure 1). While the baseline level of HRV analysis (EE_1) was found to only correlate moderately with EE_{IC} ($r=0.598$), the strength of the correlation did increase meaningfully when adding measured HR_{max} and VO_{2max} into the FB software (EE_3) ($r=0.722$). The correlations between EE measures during low-intensity activity were not as strong as would be desired, however support for the similarity between the measures comes from the fact that no significant differences were detected using paired t-tests, and there were only 0.66%, 4.09%, and 6.13% differences between the means of EE_{IC} and EE_1, EE_2, and EE_3 respectively. Based on these results, the use of HRV-analysis in place of IC during low-intensity activity is warranted, however it is recognized that EE outputs are likely slightly less than actual values.

However, the differences do not appear to be large enough to alter the overall interpretation of the energy demands of the activity being analyzed. These results are consistent with the findings of Montgomery, et al. [14], who also indicated slight underestimation of EE from HRV analysis in comparison to that obtained from IC during moderate to high intensity activity.

During maximum intensity activity, intraclass correlations for the VO_{2max} test between EE estimations from the FB software and those obtained from gas-exchange analysis were strong (see Figure 2) and provide support for the use of HRV-based EE estimation, in place of IC, for high-intensity activities. Interestingly, the correlation between EE_1 and EE_{IC} (r=0.844) was essentially the same as that which used the predicted VO_{2max} from the basic level of analysis (EE_2) (r=0.850). This indicates that allowing the software to perform the analysis with just baseline participant information and predicted HR_{max} is a suitable option for high-intensity activity analysis. If however measured HR_{max} and VO_{2max} values are available, they should be used as the software analysis with those values included (EE_3) provides a stronger correlation with IC (r=0.973). Paired t-tests between the HRV analysis conditions and IC showed no significant differences, and there were only 5.69%, 1.17% and 0.39% differences between the means of EE_{IC} and EE_1, EE_2, and EE_3 respectively, indicating that HRV-analysis is a viable substitute for IC during high-intensity activities without the need for individual device calibration beyond baseline measures.

During free-living activity, the FB analysis conditions correlated strongly amongst themselves indicating that similar EE measures would be obtained whether using basic participant information or performing testing to obtain HR_{max} and VO_{2max} values. This point is further supported by the negligible difference (4.2%) between the baseline analysis condition (EE_1) and that using measured HR_{max} and VO_{2max} values (EE_3). Because of the strong relationship found between EE measures from all HRV analysis conditions and IC, across the full range of physical intensities, we were able to assume that the HRV-based EE measures for daily free-living activity were sufficiently close to those that would be obtained if IC was a viable option for free-living activity. Based on the marginal differences between the EE measurements across the difference analysis conditions, the use of only baseline information, without the need to perform testing to obtain HR_{max} and VO_{2max} values, is supported.

5. Conclusions

The results of this study confirm that the use of HRV-based EE estimation without the need to perform individual device calibration beyond baseline participant measures (age, height, weight, HR_{rest}, HR_{maxP}, activity level) can be used. HRV-based EE measures improve in relation to IC-based measures when measured HR_{max} and VO_{2max} values are included, therefore with individuals and populations where the testing to obtain these measures is not a health risk it is advised that they are obtained and used for analysis to ensure the best possible accuracy in relation to IC. The ability of HRV analysis to provide long-term time/activity specific EE monitoring during free-living activity is its most appealing advantage over IC. Additionally, the information it provides is useful in terms of exercise prescription, health maintenance, physical capacity assessment, and activity monitoring [1, 2, 8, 18]. Typically these applications are relevant individuals where the tests to obtain HR_{max} and VO_{2max} measures would be contraindicated [4]. Because of this, verifying that accurate EE measures can be obtained using baseline participant information is of the utmost importance.

Whereas the study by Montgomery et al. [14] was conducted in well-trained athletes, this study used non-elite athlete subjects to draw conclusions regarding the accuracy of HRV-based EE estimations in a general population of individuals. Thus, in addition to justifying the use of HRV monitoring in at-risk populations and individuals, we have shown that this technology is appropriate for use in healthy, working, non-elite athlete populations and individuals wherein HRV monitoring is useful for the same purposes. In these cases however, it is advised that if time and resources allow, the necessary testing to obtain the values that improve accuracy should be performed. It should be noted that based on the low-intensity results, underestimation in HRV-based EE estimations may occur in daily free-living usage during sedentary and sleep periods, and this should be considered when interpreting the EE measures in free-living conditions. The underestimation however is not clinically significant and the data may still be used to provide useful recommendations. Further technological development and research into how to improve EE estimations under these conditions is recommended. More specifically, future research should be conducted to determine how the software algorithm might be recalibrated to even more accurately estimate EE across the full range of physical intensities. Ultimately, the benefits inherent in this technology outweigh its limitations and the results show that EE measures obtained through HRV data analysis in FirstBeat SPORT software can be used with confidence.

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Conflict of Interest

The authors declare no conflicts of interest.

Author Contributions

SD, SR, and AG were involved in the conception and design of the study KK and ML recruited participants and collected the data. AR was responsible for data/statistical analysis and interpretation, and drafting of the article manuscript. KK, ML, SR, AG, and SD were involved in editing of the manuscript. All authors read and approved the final manuscript.

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Chapter 3

Assessment of physiological demands and nutritional practices of Ontario FireRangers during fire deployment.

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Abstract

Introduction: The seasonal profession of wildland fire-fighting in Canada requires individuals to work in harsh environmental conditions that are physically and mentally demanding. Fatigue has been cited as a contributing factor to the high annual injury rates observed in FireRangers. In order to assess potential modifiable determinants of fatigue, the purpose of this study was to pilot test novel tools to evaluate the physiological demands and nutritional practices of Ontario FireRangers during fire deployments.

Methods: Participants (n=21) from a Northern Ontario Fire Management Headquarter volunteered in this study and data collection occurred during Initial Attack (IA), Project Fire (P), and Fire Base (B) deployments during the 2014 fire season. Deployment-specific energy demands and physiological responses were measured using heart-rate variability (HRV) monitoring devices (Zephyr BioHarness3 units), and audio-video food logs maintained using iPod Touches were analyzed in NutriBase Pro11 software.

Results: FireRangers expended the most energy during initial attack deployments, and the least during base camp deployments. Insufficient kilocalories were consumed relative to daily energy expenditure resulting in negative energy balance for all observed deployment types; furthermore, nutritional quality was found to be inadequate.

Conclusions: The results of this study indicate the need to develop strategies centered on maintaining physical fitness and improving food practices. This study is the first to use the described methodology to comprehensively evaluate physiological demands and nutritional practices simultaneously in an occupational setting and provides support for the use of this methodology in future occupational research.

Keywords →fatigue, energy expenditure, stress, recovery, energy balance, nutritional quality

Introduction

Canadian FireRangers are responsible for protecting rural communities and the vast Canadian landscape from the destructive force of wildland fires. FireRangers are continuously exposed to a multitude of environmental hazards during fire deployment, including: unpredictable fire behaviour and weather, unstable and rough terrain, heat, and smoke while transporting and operating heavy equipment; all of which pose both acute and chronic risks to their health. Thus it is perhaps not surprising that FireRangers exhibit the highest injury rates among all workers within the Aviation, Forest Fire, and Emergency Services (AFFES) division of the Ministry of Natural Resources and Forestry (MNRF) in Ontario, with the main mechanisms of injury being: slips/trips/falls and use of equipment/tools/machinery[9,10,11,12]. These statistics are similar to observations of FireRangers from other countries[18].

Harsh working conditions and prolonged fire suppression activities are a concern for the MNRF as fatigue has been frequently cited as a causal factor for the injuries sustained by

FireRangers on deployment[9,10,11,12]. Fatigue in this context refers to reduction in mental and/or physical performance (i.e. slowed reactions, decreased awareness, attention lapses, reduced coordination) that can result from prolonged physical exertion, sleep loss, lack of recovery, stress and anxiety, and inadequate nutrition[3,20]. During fire deployment, the severity of each contributing factor cumulatively impacts FireRanger fatigue and therefore their likelihood of sustaining injury. Unfortunately, some contributing factors are inherent to the occupation (i.e. hazardous environmental conditions, and unpredictable emergency responses); however certain factors such as physical fitness and nutritional practices are under FireRanger control and can serve to mitigate fatigue. These modifiable determinants of fatigue may be addressed through targeted interventions toward the goal of reducing the rate of FireRanger injury.

As described by AFFES, the fire suppression activities of FireRangers can be divided into three distinct categories: Initial attack; Project; and Base Camp deployments. Each category of deployment requires examination to understand specifically how FireRangers engage themselves physically and differentiate their eating behaviours based on the context of their work activities. Initial Attack (IA) deployments, involve first-response, fire-suppression duties; physical activity is intense and duration of deployment varies according to fire intensity. Initial Attack (IA) deployments require FireRangers to be positioned into remote, unsettled locations to contain fires before they become uncontrollable. Project fires (P) are typically of longer duration than other deployments and include prolonged, moderately intense physical activity involving duties related to the clean up of debris and smoulder extinction once a fire has burned through an area of land. Fire base activities (B) are those that are performed when FireRangers are not on deployment but are reporting daily to the Fire Management Headquarters (FMH) to ensure personnel and equipment are prepared for immediate deployment and for training and education.

While the deployment lengths of MNRF FireRangers are similar to those of wildland fire fighters in other countries, there exists a lack of research on the physical demands specific to wildland fire suppression unique to the Canadian landscape. Research on wildland fire fighters in other parts of the world has highlighted the intense physical demands inherent in this profession. Through the use of doubly-labelled water (DLW) and electronic activity monitors[39,63], energy expenditure (EE) estimates of ~4500kcal/day have been shown in Australian and American wildland fire fighters indicating that the daily energy demands of wildland fire fighting are comparable to those of military personnel during combat training[71], and athletes during training and competition[28,60,78]. Although doubly-labelled water is a highly accurate estimate of energy expenditure[2,6,58]; it cannot qualitatively describe the spread of energy expenditure over a work-day. In contrast, heart rate variability (HRV) monitors can demonstrate moment-to-moment energy expenditure as estimated by the surrogate measure of heart rate rhythm[29,53,61]. The accuracy of HRV-based energy expenditure estimates has been previously validated against indirect calorimetry in the laboratory setting[29,53,61]. HRV measures can also provide data regarding amount of time spent in physical activity, stress and recovery as defined by FirstBeat Technologies based on the relationship between HRV and autonomic nervous system activity[31]; these devices have yet to be used in occupational settings.

Based on the intense physical demands observed in this profession the need for adequate intake of quality nutrients is implied, yet wildland fire fighters have previously been found to operate with a negative energy balance of ~500kcal/day[63]. A barrier to quality nutritional intake while on fire deployment are the available food supplies. Montain and colleagues (2008) found that wildland fire fighters consumed higher proportions of supplied foods when served in snack-based forms (83%) as opposed to entrée-based forms (78%)[52]. It is important to note that the total energy contained in both forms of food supplies equated to only ~3000kcal/day and therefore well below the estimated daily energy output reported previously[63], presumably leaving wildland fire fighters in a state of negative energy balance even with 100% ration consumption. In addition to the importance of maintaining adequate energy balance during prolonged periods of intense physical activity, it is also important that the nutritional quality of foods consumed meet demands for optimal functioning and tissue recovery. Based on the authors' understanding, there have been no studies that have examined energy expenditure and food consumption simulataneously amongst FireRangers; considered these variables under varying deployment conditions; nor examined the macronutrient and micronutrient consumption patterns of these workers.

The literature highlights the need to perform a more detailed assessment of the energy demands and nutritional habits specific to Ontario FireRangers in order to more effectively develop strategies specific to their unique working environment. Therefore, the purpose of the study was to use novel tools to: i) quantify daily energy expenditure and food consumption in FireRangers; ii) qualify the deployment-specific energy demands and physiological responses of FireRangers; and iii) assess the nutritional quality of foods consumed by FireRangers, all based on deployment type.

Methods

Participants

During the 2014 fire season, twenty-three FireRangers participated in this study. Two participants withdrew from the study: one sustained an injury and was therefore absent from the workplace; and one voluntarily withdrew for personal reasons, resulting in a final sample of twenty-one participants (n=21). All participants provided written informed consent prior to the start of data collection, and this study received ethics approval from the Laurentian University Research Ethics Board. All participants (n=21) were male with a mean age of 29.8 ± 8.5 years, height of 180.6 ± 8.1cm, weight of 85.3 ± 11.8kg, and activity class of 7.0 ± 0.6 (self-reported according to FirstBeat activity class categories)[30].

Study Design

Members of the research team met prospective participants (18 crews x 4 FireRangers = 72 potential participants) on two occasions prior to the start of the 2014 fire season for recruitment purposes. Upon receiving informed consent (n=23; 32% response rate), the research team met with the participants to collect baseline information (age, height, weight, Heart Rate (HR_{rest}, HR_{max} ($HR_{max} = 208 - 0.7age$))[71], activity level[30], and provided individual training to the participants on the data collection protocols as well as operation and maintenance of the data collection equipment. As a support resource, instructional videos and images detailing all aspects of the aforementioned training were loaded onto iPod Touches© provided to each participant. Participants were also provided with researcher contact information if further assistance was required, as well as for in-season correspondence. Participating FireRangers were asked to carry several small pieces of data logging equipment with them throughout the season: a BioHarness3 HRV monitor, an iPod Touch, an ActiSleep monitor, and a compact battery to charge the devices as necessary (Anker Astro Pro2 20000mAh Multi-Voltage External Battery). Participants were instructed to carry and utilize the equipment during all deployment types throughout the fire season and use them until they returned from each deployment, at which time the data would be downloaded and the devices returned to participants prior to their next deployment. FireRangers were not assigned specific days on which to collect data given that fire activity is unpredictable.

Instead, FireRangers were provided with an individual equipment package and were responsible for initiating use of the equipment upon notice of fire deployment. FireRangers were also asked to collect data during extended periods in which they were aware they would be spending their shifts solely at the fire base. During deployments, participants were instructed to initialize and wear their BioHarness3 module upon waking in the morning until going to sleep at night, at which time they were required to charge the device overnight. From sleep onset until waking, participants were instructed to wear the ActiSleep monitor. These latter devices were not worn during the day due to concerns regarding exposure to water and submersion that would exceed their functional capacity. Additionally, during each day of data collection, participants were instructed to use the video recording function of the iPod Touch to document all food consumed.

Heart Rate Variability (HRV) Monitoring

HRV monitoring was used to estimate the energy expenditure of FireRangers during deployments. BioHarness3 units from Zephyr Technologies (Annapolis, Maryland) were selected as they were specifically designed for use in athletes and emergency responders[82]**.** HRV measures are also representative of autonomic nervous system activity (i.e. parasympathetic and sympathetic activity), therefore HRV analysis was used to characterize the demands of FireRangers' varied working conditions with corresponding physiological reactions (i.e. physically active, physiological stress, and physiological recovery) simultaneously[29,31]. The FirstBeat SPORT software defines:

physical activity - as periods in which an individual exceeds 30% of their HR-derived VO_{2max};

stress - as periods in which sympathetic nervous activity is dominant in relation to parasympathetic nervous activity; and

recovery - as periods in which parasympathetic nervous activity is dominant in relation to sympathetic nervous activity[30].

Additionally, periods not categorized as any of the aforementioned states is defined as "other"[31]. Using this categorization, the FirstBeat SPORT software produces reports for each day logged by participants, representing each category as a percentage of total device wear time.

Each participant was provided with an individually calibrated (age, height, weight, HR_{rest}, HR_{max}) BioHarness3 module and chest strap, as well as a charging cradle and portable battery pack. Participants wore the monitors during waking hours and removed the unit for charging when going to sleep each day.

Sleep Monitoring

Total sleep time (TST) was measured using ActiSleep monitors from ActiGraph. This wrist-worn device uses accelerometry to measure TST, has been validated against the gold-standard of polysomnography, and been deemed ideal for use in field studies with healthy individuals[4,8,64,65]. Average FireRanger TST was used for the purpose of determining 24hr energy expenditure.

Food Logs

During Base Camp and Project deployments, each FireRanger was provided an iPod Touch to estimate energy intake (EI) and nutritional quality data, through use of the audio-video recording function. FireRangers were instructed to film the contents of their meals while simultaneously dictating portion sizes and ingredients that are unapparent from the visual alone (e.g. coffee in portable container). This method is a novel adaptation of the photographic food-logging method that has been used successfully in previous research[26,33] and has been deemed to be a more accurate and reliable method than self-report methods (i.e. recall)[43,49,50,80]. FireRangers were unable to self-record food consumption during Initial Attacks, due to the nature of this type of deployment, therefore IA food data were examined differently. IA deployments are only two, consecutive days; during this time, pre-packaged, frozen and dry foods are dropped with the FireRangers and are the *only* foods available to them until supply runs can reach their location. Therefore, researchers photographed all contents of the IA foods provided to FireRangers and, assuming FireRangers divided the foods equally amongst their crew, subsequently determined individual FireRanger daily food availability.

HRV Data Analysis

The raw HRV (R-R interval) data extracted from the BioHarness3 units were analyzed using FirstBeat SPORT software (Jyväskylä, Finland). Individual profiles were created using participant baseline information (age, height, weight, HR_{rest}, HR_{max}, activity class) according to software calibration requirements[30,61].

Nutrition Data Analysis

The contents of the P and B food logs and the contents of IA food photos were inputted into NutriBase Pro 11.0 nutritional analysis software (Phoenix, Arizona) allowing for detailed energy intake, as well as macro- and micronutrient analysis.

The results of the food log analyses were then compared to established energy intake, macro- and micronutrient recommendations[36,37,38]. Since it is recommended that a minimum of three, consecutive days of food data is required to adequately represent food consumption patterns[34,81], only deployments with a minimum of three consecutive days were analysed for macro- and micronutrient content for each type of deployment.

Daily Energy Expenditure

Given the need to charge the BioHarness3 units nightly, 24hr HRV monitoring was not possible. Upon downloading the data from the devices, it was observed that participants did not wear the BioHarness3 continuously from the time they woke up until they went to bed, as requested (See Table I). Therefore, 24hr Energy Expenditure (EE) was estimated using: individual, average, and hourly EE observed for each deployment type; average sleep time (obtained from ActiSleep data); and MET values from the Compendium of Physical Activities7. Based on the working time guidelines set for FireRangers, the maximum of 16hrs/day was multiplied by EE1hr for each type of fire deployment (IA and P); a) This provides an estimation of the maximum daily energy expenditure specific to each deployment type relative to the intensity observed during the 2014 fire season; b) Estimating daily energy expenditure using a shorter shift length (e.g. 50% of maximum daily working hours – 12hrs/day) would mean having to infer participant activities for the remaining hours, decreasing the ability of the estimations to reasonably represent each deployment type. For B deployments 12hrs/day was used for daily EE estimation, as this is the length of shift FireRangers work during days spent at headquarters. A total of 12 participants wore the ActiSleep monitor on 152 nights throughout the 2014 fire season, and average TST regardless of deployment type was found to be 364 ± 61.2min/night (~6 ± 1hrs/night). This finding is consistent with the TST observed in Australian wildland firefighters during deployments75,77. Accordingly, 6hrs/night was used for daily energy expenditure estimation by multiplying this value by the corresponding Compendium of Physical Activities value for sleeping (1.0METs)7. For IA and P deployments, the remaining 2hrs, and

6hrs for B deployments, were conservatively estimated using the MET value for sitting/standing quietly (1.3METs) as it cannot be assumed what activities FireRangers may perform during this time. The 24hr EE estimation formulas for each deployment type are listed below.

Initial Attack – $EE_{IA24est} = (16*EE_{1hrIA}) + [2*(1.3METs*kg)] + [6*(1METs*kg)]$

Project Fire – $EE_{P24est} = (16*EE_{1hrP}) + [2*(1.3METs*kg)] + [6*(1METs*kg)]$

Fire Base – $EE_{B24est} = (12*_{EE1hrB}) + [6*(1.3METs*kg)] + [6*(1METs*kg)]$

Statistical Analysis

All statistical analyses were performed using IBM SPSS 20 (Armonk, New York). Results are shown using the mean ± SD. One-way ANOVA's were used to determine significant differences between deployment-specific energy expenditure, physiological reactions, and energy balance. Independent t-tests were used to detect significant differences between energy intake and macronutrient/micronutrient profiles for P and B deployments; IA energy intake and macronutrient/micronutrient profiles were established from the available IA food supplies and therefore did not have a distribution of values that could be used in an ANOVA for comparison with the corresponding P and B values. Significance was accepted at the level of $p<0.05$.

Results

Participants

All participants (n=21) were male with a mean age, height, weight and activity class of 29.8 ± 8.5 years, 180.6 ± 8.1cm, 85.3 ± 11.8kg, and 7.0 ± 0.6 respectively.

Deployment-Specific Measures: Initial Attack (IA), Project Fire (P) and Fire Base (B)

Tables I and II list all deployment-specific descriptive statistics for all variables considered. Figures 1, 2, and 3 display the data graphically and indicate where statistically significant ($p<0.05$) differences were found across deployment types.

Below is a summary of the differences in these data.

Energy Expenditure $(EE)_{1hrIA}$ was significantly higher than EE_{1hrP} ($p=0.014$), and EE_{1hrB} ($p=0.000$), and EE_{1hrP} was significantly higher than EE_{1hrB} ($p=0.001$).

EE_{peakIA} and EE_{peakP} were significantly higher than EE_{peakB} ($p=0.000$, $P=0.013$ respectively). EE_{peakIA} was not significantly higher than EE_{peakP} ($p=0.065$).

$EE_{IA\text{-}24hr}$ and $EE_{P\text{-}24hr}$ were significantly higher than $EE_{B\text{-}24hr}$ ($p=0.001$, p-0.027 respectively). $EE_{IA\text{-}24hr}$ was not significantly higher than $EE_{P\text{-}24hr}$ ($p=0.560$)

See Table I and Figure 1.

A significant difference between Energy Balance $(EB)_{IA}$ and EB_P (p=0.038) was found, but not between EB_{IA} and EB_B (p=0.513). No significant difference was found between $EB_{IA\text{-}80\%}$ and EB_P (p=0.918) nor between $EB_{IA\text{-}80\%}$ and EB_B (p=0.802).

See Table I and Figure 1.

There was no significant difference between Energy Intake $(EI)_P$ and EI_B in terms of %protein (p=0.534), %carbohydrates (p=0.828), and %fat (p=0.618). No significant differences among micronutrients were found between P and B deployments.

See Table II and Figure 2.

Total time engaging in Physical Activity during IA deployment was not significantly greater than P deployments (p=0.055), however it was significantly greater than B deployments (p=0.001).

Total time spent in Stress during IA deployments was significantly higher than P deployments (p=0.001), but not greater than B deployments (p=0.089). There were no differences between P and B deployments.

Total time spent in Recovery during IA deployment was significantly lower than P (p=0.002) and B deployments (p=0.001). There were no differences between P and B deployments.

See Table I and Figure 3.

Table I: Deployment-specific results (see Table II for deployment-specific food log descriptive statistics and macronutrient/micronutrient profiles)

	Deployment Type		
	Initial Attack (IA)	Project Fire (P)	Fire Base (B)
Total participants (HRV Data)	15	10	13
Total HRV shift logs (days)	37	36	35
Mean shifts logged per participant (days ± SD)	2.6 ± 1.1	3.6 ± 1.4	2.7 ± 1.6
Mean BioHarness3 log time (hours ± SD)	8.9 ± 3.7	11.5 ± 2.5	10.6 ± 2.4
Mean hourly energy expenditure (kcal/hr ± SD)	250 ± 61.9	202 ± 79.4	137 ± 51.1
Mean peak energy expenditure a) (kcal/min ± SD) b) (METs ± SD)	a) 16 ± 2.6 b) 11.3 ± 1.6	a) 14 ± 4.9 b) 9.9 ± 3.2	a) 11 ± 4.1 b) 8.1 ± 3.4
Mean daily energy expenditure (kcal/day ± SD)	4538 ± 1006.3	4021 ± 1164.8	2842 ± 649.9
Mean daily energy intake (kcal/day ± SD)	100% = 4698 80%* = 3758	2945 ± 888.8	2433 ± 570.8
Mean daily energy balance (kcal/day ± SD)	100% = 160 ± 1006.3 80%* = -780 ± 1006.3	-1063 ± 1499.0	-409 ± 851.9
Mean physiological response profile (% total log time)	22.5 ± 10.3% - Physical Activity 15.8 ± 13.9% - Stress 14.4 ± 18.9% - Recovery 47.3 ± 16.6% - Other	16.4 ± 11.7% - Physical Activity 4.6 ± 6.0% - Stress 32.3 ± 23.4% - Recovery 46.7 ± 24.3% - Other	8.3 ± 6.0% - Physical Activity 8.6 ± 14.6% - Stress 63.3 ± 23.5% - Recovery 19.8 ± 14.0% - Other

* Previous research regarding food consumption patterns in wildland fire fighters indicated an 80% consumption rate of provided rations[52]

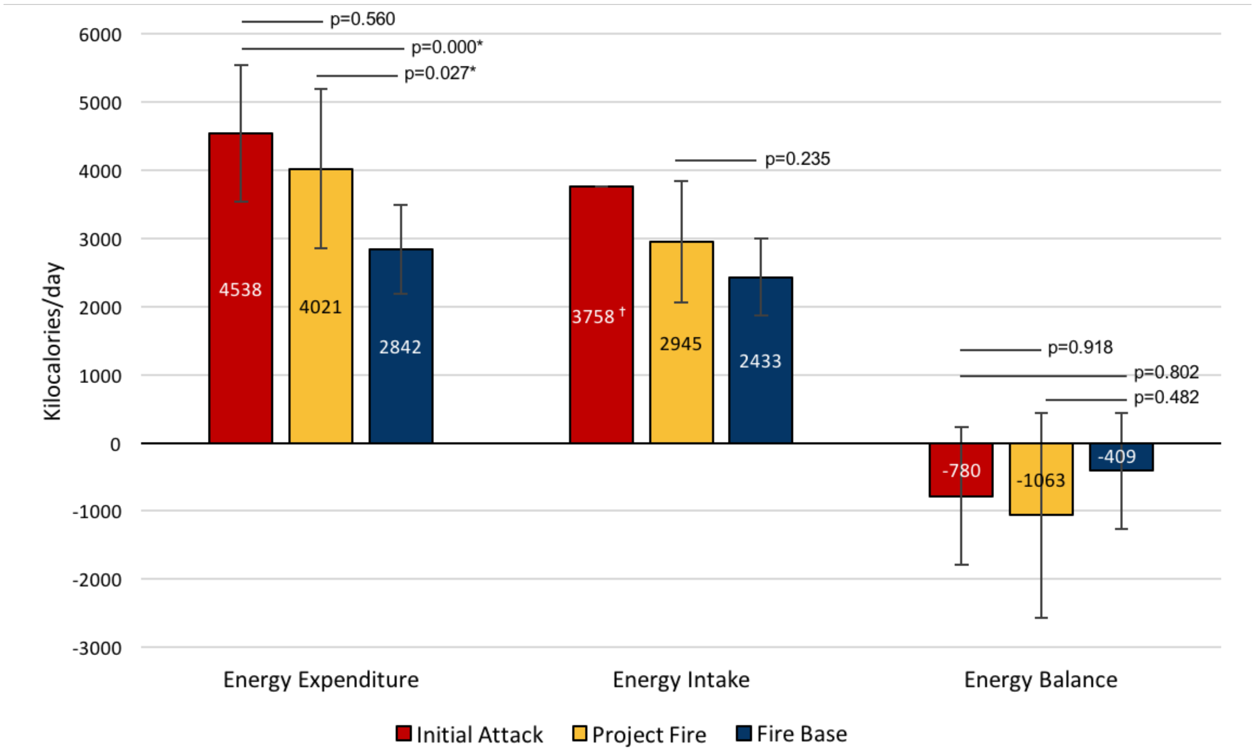
Table II: Deployment-specific food log descriptive statistics, macronutrient profiles, and micronutrient consumption relative to recommended dietary allowance (RDA) and adequate intake (AI) guidelines[38]

	Deployment Type		
	Initial Attack	Project Fire	Fire Base
Total participants (Food Logs)	NA**	5	7
Total food logs >3 Days*	NA**	6	7
Mean shifts logged (days ± SD)	NA**	4.2 ± 0.8	4.7 ± 1.6
Mean Macronutrient Profile (% total intake ± SD)	23% - Protein 27% - Carbohydrates 50% - Fat	22 ± 7.1% - Protein 37 ± 8.4% - Carbohydrates 41 ± 6.9% - Fat	25 ± 9.1% - Protein 36 ± 4.3% - Carbohydrates 39 ± 7.7% - Fat
Fiber (%AI)	68.4	80.7 ± 35.6	66.2 ± 49.4
Iron (%RDA)	347.5	270.8 ± 81.6	219.6 ± 97.3
Magnesium (%RDA)	50.1	87.5 ± 27.6	61.4 ± 49.6
Selenium (%RDA)	181.3	375.5 ± 179.3	231.4 ± 131.3
Zinc (%RDA)	151.8	150.0 ± 50.4	105.2 ± 36.3
Phosphorus (%RDA)	162.2	278.8 ± 143.7	179.6 ± 120.6
Calcium (%RDA)	135.9	93.9 ±35.2	82.1 ± 24.8
Sodium (%AI)	369.4	310.7 ± 142.6	279.9 ± 134.3
Potassium (%AI)	32.5	80.4 ± 26.6	53.4 ± 37.4
Vitamin A (%RDA)	96.0	246.3 ± 210.9	148.4 ± 195.4
Vitamin B12 (%RDA)	241.7	375.0 ± 320.6	333.3 ± 302.4
Vitamin C (%RDA)	34.4	146.3 ± 58.1	151.3 ± 259.3
Vitamin D (%RDA)	62.4	42.8 ± 52.9	16.9 ± 13.4
Vitamin E (%RDA)	58.5	116.1 ± 143.8	40.2 ± 33.1

* Food records must be kept for a minimum of 3 consecutive days to be used for analysis[34,81]

** Initial Attack (IA) deployments are classified as less than 48hrs, therefore contents of pre-packaged IA food supplies to be sent on deployments were photographed and used for analysis.

Figure 1: Deployment-specific daily energy expenditure, energy intake, and energy balance



† Energy intake based on 80% consumption[52] of IA food supplies

Figure 2: Deployment-specific macronutrient profiles

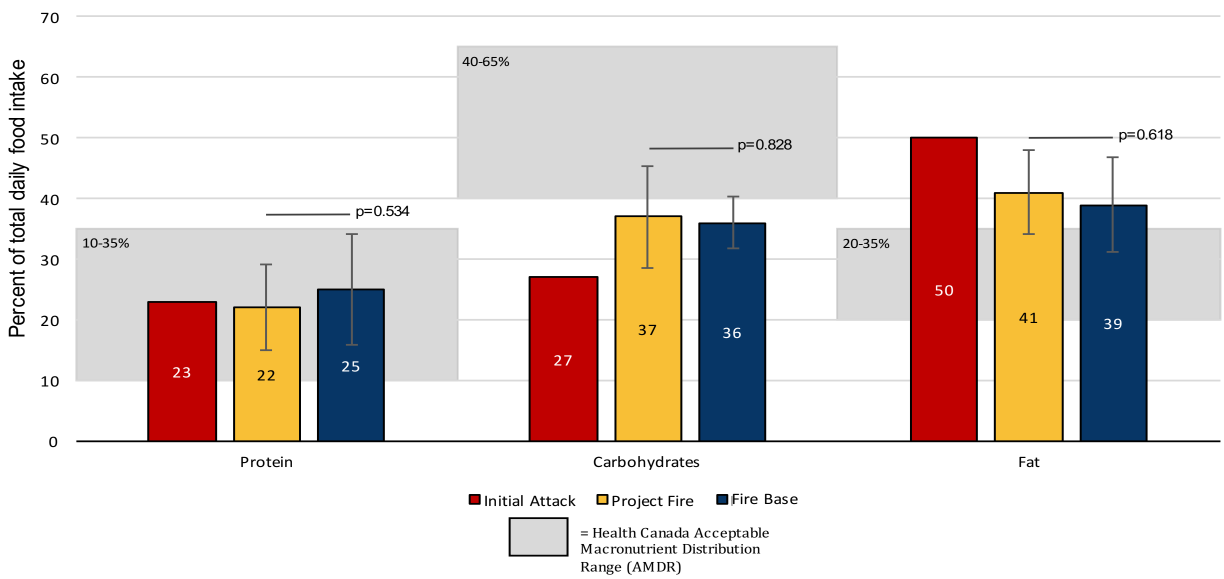
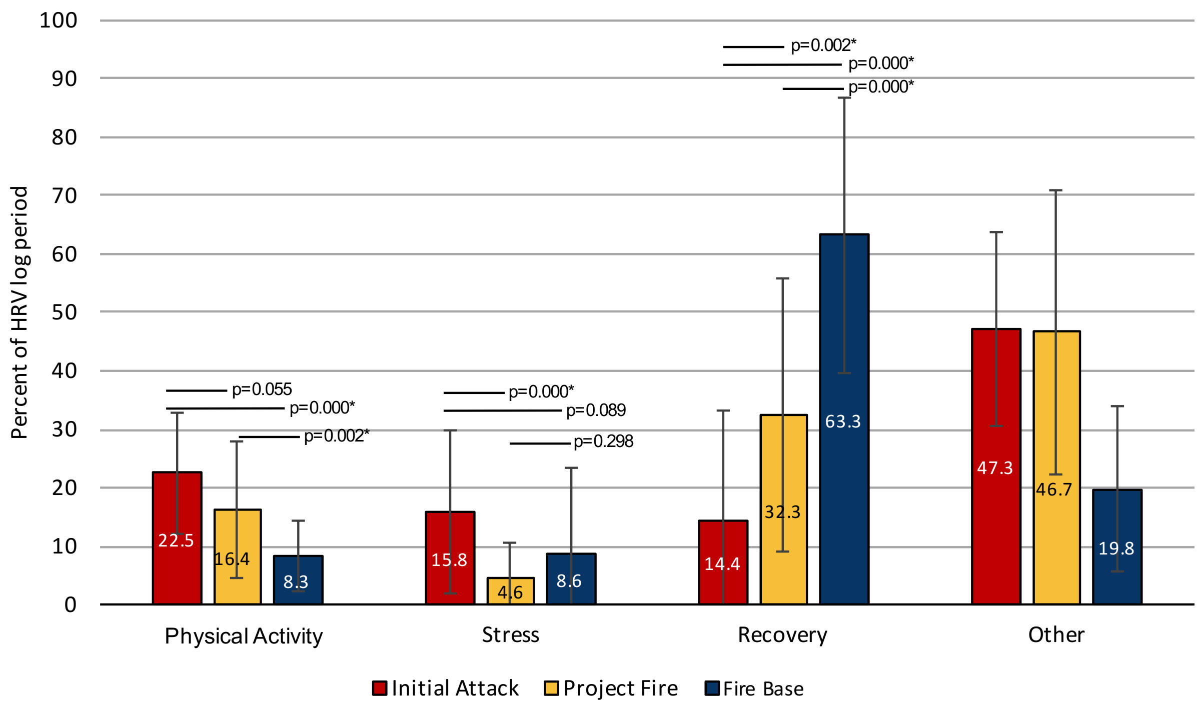


Figure 3: Deployment-specific percentage time spent in periods of physical activity, stress, and recovery



Discussion

Using a novel methodology consisting of mobile monitoring technologies, the data obtained during the 2014 fire season highlighted several areas which may be potentially targeted with fatigue-mitigation intervention strategies.

HRV monitoring has been previously shown to be a valid measure of energy expenditure estimation in the laboratory and during free-living conditions[29,53,61]. In this study, for the first time, HRV monitoring was used in an occupational field setting. Our energy expenditure estimates reflect data previously collected in the field using the gold standard of doubly-labeled water[39,63] and support the use of this methodology for data collection in the field.

This study also showed that the video adaptation of the photographic dietary assessment methodology previously validated in the literature[26,33,43,49,50,80] is possible in complex field environments such as wildland fire deployments. Audio-video recording of meals, allows for the independent collection of food data under free-living conditions, replacing previous self-report data collection methods (e.g. survey, diary, recall), which are largely considered to be inaccurate and unreliable[25,67,68]. This study suggests that participants were accepting of the audio-video methodology, providing support for further use of this method in future research. Photographic diaries have also previously been shown in the literature to be preferred by study participants over the aforementioned self-report methods[49], which is advantageous given established weaknesses of the latter[25,67,68].

Activity Intensity

The data from this study confirmed that the fire suppression activities performed by Ontario FireRangers are physiologically intense[7]. Consistent with the trend noted by Rodriguez-Marroyo and colleagues (2011) in their research on wildland firefighters, our data suggest that IA deployments were of significantly higher physical intensity than P deployments. Understandably, both types of fire deployments (IA and P) were shown to be of significantly higher intensity than days spent at the Fire Base (B), where FireRangers train and prepare for deployments. Furthermore, a marginally significant difference was noted between the peak energy expenditures during IA and P deployments, however both were significantly greater than peak energy expenditure while at base. To contextualize the energy expenditure values noted for the various deployment types, the measures were converted to METs (kcal/kg/hr) allowing comparison with activities comprising the Compendium of Physical Activities[7]. These comparisons indicated that at peak intensity, FireRanger's tasks during fire deployment are more intense than structural fire fighting (7-9METs), and comparable to competitive ice hockey and soccer (10METs) as well as cross-country running (9METs)[7]. The Compendium of Physical Activities supports this finding by listing the task of inclined walking while carrying 50-74lbs as 10METs[7], a task regularly performed by FireRangers who carry heavy equipment and supplies across rough terrain. Comparison of FireRanger energy demands to those of highly intense physical activities provided a pragmatic method with which to contextualize the profession in terms of intensity, providing support for the notion that FireRangers are "occupational athletes". During an average intensity fire season[5] the hourly average and peak energy expenditures would likely be higher and occur more frequently. Notably, the 2014 fire season, in Ontario, was one of the lowest intensity fire seasons recorded in recent years[5]. The spectrum of observed activity intensities that comprise wildland fire suppression duties is critical to consider when developing structured fitness programs as well as considering nutrient needs.

Energy Balance

Given the physical demands of this occupation, it is important that FireRangers be both physically fit and adequately fuelled. Estimates of daily energy expenditures during IA and P fire deployments are consistent with values found in previous research on wildland firefighters elsewhere in the world[39,63]. Twenty-four hour EE was found to be significantly higher during fire deployment relative to days spent at the fire base, indicating that fire suppression duties substantially increase daily energy expenditure relative to preparatory activities performed at the headquarters. This finding is in line with the observed differences in activity intensities across deployment types. The 24hr EE estimates during a low-intensity fire season are comparable to daily energy expenditure values observed in military personnel[72] and in professional soccer players and cyclists during training and competition[28,60,78]. This provides support for adopting structured military and professional athlete fitness practices for these workers.

The audio-video food diaries provided valuable insight into the quantity of kilocalories consumed during deployment to support performance of the aforementioned energy intensive work-activities. Since IA deployments use packaged food only, we were only able to estimate food consumption during these deployments using a calculated 80% of supplied foods[52] or 3758kcal/day consumed. Average food consumption during P and B deployments were found to be consistent with the daily energy intake observed in American wildland firefighters (~3000kcal/day) by Montain and colleagues (2008). While also consistent with the daily energy intake of Canadian adults in the same age range (~3000kcal/day)[69], the data indicates that

FireRangers daily energy intake is typically less than energy expended and equivalent to Health Canada's recommendations for *moderately* active adults[37]. Given that FireRangers perform tasks equivalent to the intensity of competitive sports, in which it is well established that daily energy intake requires augmentation, kilocalorie enhancement in this population represents a key modifiable factor related to fatigue development and injury risk.

The negative values for energy balance during IA and P deployments indicate that while some FireRangers are consuming sufficient kilocalories, as evidenced by the large standard deviation, on average FireRangers do not consume enough food during a shift to match the energy demands of their work activities. The same was found during days spent at the fire base, indicating that simply being on fire deployment is not the root cause of the observed negative energy balance values. The observed daily, negative energy balance values in Ontario FireRangers are consistent with previous studies in other populations of wildland fire fighters in which food supplies relative to the energy demands of their work activities reportedly contained insufficient kilocalorie content[39,52,63]. Particularly concerning about these findings is that extended periods of caloric restriction substantially impacts physical performance[3,32,41,57]. Furthermore, weight loss and muscle wasting, as well as decreased strength and performance, immune function, energy levels, and alertness can all result from daily negative energy balance[3] and may compound upon one another, leading to injury[70]. Since energy balance is a determinant of fatigue that is modifiable without altering any existing workplace structure or procedures, it is advised that intervention strategies (i.e. workshops, eLearning modules etc…) be implemented aimed at increasing FireRanger daily energy intake to match the energy demands of specific deployment types.

Nutritional Quality

In addition to the need for sufficient kilocalorie consumption to support activities, it is also important that workers consume appropriate amounts of macro and micronutrients. Recommendations regarding daily macronutrient consumption for both the general population and athletes indicate that 10-35% of kilocalories should come from protein, 45-65% from carbohydrates, and 20-35% from fat[3,36]. In research on American wildland firefighters, Ruby et al. (2002) found macronutrient distributions of 53 ± 7% carbohydrate, 14 ± 2% protein, and 32 ± 6% fat[63], and Cuddy et al. found macronutrient distribution ranges of 59 ± 6% carbohydrate, 12 ± 3% protein, and 31 ± 7% fat[24]. Our results indicate that, regardless of deployment type, FireRangers exceed daily fat intake and do not meet recommended carbohydrate intake, however protein intake was within an acceptable range[3,36] (Figure 2). FireRangers were also found to deviate from recommendations for athletes regarding daily macronutrient consumption relative to body weight (1.2-1.7g/kg protein and 6-10g/kg carbohydrates)[3]. FireRangers consumed 2.5g/kg, 1.9g/kg, & 1.8g/kg protein and 3.5g/kg, 3.4g/kg, & 2.8g/kg carbohydrates during IA, P, and B deployments respectively. Protein consumption relative to bodyweight was found to be over twice as much as Health Canada and Institute of Medicine (0.8g/kg/day) recommendations[38,44]. However, given the high intensity and prolonged periods of exercise FireRangers engage in, these levels are in line with those consumed by athletes and are not considered to be a point of concern[3,38,44]. Research regarding potential long-term health concerns, including kidney damage and calcium excretion, has indicated that these concerns are unfounded but does acknowledge the need for more robust research into the topic[17,51,73]. It is quite common for athletes to augment their protein intake to promote muscle and tissue recovery and there is evidence to support this practice[3,54]. The current protein consumption exhibited by FireRangers in the present study already meets and exceeds these recommendations therefore no modification is likely required. The excessive fat intake exhibited by FireRangers is however a potential concern, as this practice can lead to undesirable cardiovascular consequences both acutely[42,46,79] and chronically[44].

However, the most significant finding in regards to the nutritional practices for FireRangers is the inadequate carbohydrate consumption, being about half of the recommended intake[3,44,54]. This is a concern because carbohydrates are essential for maintaining performance during high-intensity activities and prolonged activity at any intensity, as well as for replenishing muscle glycogen stores following these activities[3,14,15,19,24,47,54]. Carbohydrates blunt inflammatory responses from prolonged moderate-high intensity activity, protecting the person from increased risk of infection and assisting with muscle recovery and repair[55,56,66]. Importantly, carbohydrates are required for production of key hormones involved in muscle building, including testosterone and growth hormone[16]. It is therefore imperative that FireRangers increase their carbohydrate consumption to meet the aforementioned guidelines in order to provide the fuel necessary to achieve optimal and safe workplace performance without becoming fatigued particularly during demanding fire deployments.

Micronutrient consumption profiles of FireRangers were also found to deviate from established recommendations[38] (Table II), which may adversely affect their performance and health acutely and chronically. Based on the observed micronutrient consumption, FireRangers may be at increased risk of cardiovascular diseases[1,44], decreased immune function[3,40,48], and suboptimal performance[3,54]. The observed low fiber/high fat and high sodium/low potassium intake, and high iron are risk factors for developing cardiovascular diseases[1,44]. Additionally, fiber is essential for regular bowel movements[44]. A simple solution to manage the high iron intake amongst this worker population would be an annual blood donation at the end of the fire season[45].

Vitamin D and vitamin E consumption were observed to be below recommended values. However, given that wildland fire-fighting is a summer occupation, adequate vitamin D is likely achieved via the skin. FireRangers are also regularly exposed to particulate and gaseous elements from smoke that can induce oxidation, particularly in their airway[13]. Inadequate Vitamin E is concerning, particularly since this fat-soluble anti-oxidant would be beneficial for protecting cell membranes in the lining of the airways[59,74].

Deployment type largely impacts the eating habits of FireRangers. During the first two days of IA deployments FireRangers rely on pre-packaged dry and frozen food supplies that are prepared ahead of time and ready to be taken at a moments notice. The foods comprising the IA food supplies therefore consist of items that: are spoil resistant, easily transportable, quick and easy to prepare; all characteristics that are easily achieved with packaged, nutritionally sub-optimal foods. During P deployments, FireRangers typically consume communal meals for breakfast and dinner, while consuming a ration pack consisting of fruit items and various sandwiches (e.g. peanut butter and jelly, ham and cheese, chicken salad) between these meals. FireRanger eating habits during P deployments can therefore be considered a hybrid of both meal-based and snack-based food consumption, the latter of which is known to be more advantageous for occupational performance purposes[24,52]. Finally, when stationed at the Fire Base, FireRangers are responsible for their own individual diets. Although this provides opportunity for normalization of food behaviours, educational programs aimed at teaching eating strategies to optimize recovery during this down time would be beneficial, given the data presented here.

Physiological Responses

The HRV data provided interesting insight into the differing physiological reactions of FireRangers specific to each deployment type (Figure 3). Periods of physical activity were observed to be greater during IA deployments compared to P deployments, however this difference was not statistically significant. This further supports the differences in intensity between direct and indirect attacks observed by Rodriguez-Marroyo and colleagues (2011) in their research on wildland fire fighters[62]. Considering the observed differences in average energy demands between IA and P deployments, this finding is particularly interesting in that it indicates that FireRangers are performing higher intensity activities for a larger portion of their shift during IA deployments compared to P deployments. As expected, fire deployments (IA and P) were found to contain significantly higher physical activity relative to days spent working at the fire base. While FireRangers are still required to perform physical labour related to preparation for fire deployment during these shifts, this finding is positive in that it indicates FireRangers have an opportunity for rest from the intense physical demands of fire suppression activities during shifts at the fire base while they await deployment. Other research on Australian wildland firefighters has indicated that they are able to self-regulate their daily physical activity in order to maintain task performance and subjective measures of exertion over consecutive days performing fire suppression tasks[76,77]. This research showed that wildland firefighters exhibit “activity synergy” where, while still completing all tasks at the same level of performance, increased time spent in periods of light physical activity during a shift resulted in increased high-intensity physical activity during the subsequent shift[76]. These findings are positive indicators of wildland firefighter’s abilities to cope with the consistent physical demands of their occupation.

Periods of stress (i.e. sympathetic activation) were observed to be significantly lower during P fires relative to IA. This finding is unsurprising due to the nature of each deployment type; P involve predictable activities of moderate intensity, whereas IA deployments are spontaneous and involve unpredictable fire behaviour and hazardous environmental conditions. Stress, as measured using HRV analysis in this study, is representative of increased sympathetic nervous system activity[31]. Interestingly, stress was slightly higher, during B deployments compared to P Deployments. This finding, highlights the routine job structure of P Fires in comparison to IA, and could also be indicative of increased personal contributors to stress during time at home.

Adequate recovery following intense physical activity is essential for FireRangers who may be required to perform their duties for up to 14 consecutive days. Recovery, as measured using HRV analysis in this study, is representative of increased parasympathetic nervous system activity[31]. The results indicate that recovery was significantly less during IA and P deployments relative to B. This is understandable given that FireRangers can work up to 16hr/day while deployed to a fire, however it is important that they have periodic opportunities for recovery throughout their shifts as this has been shown to be an effective fatigue mitigation and performance maintenance strategy[35]. Additionally, recovery during IA deployments was significantly lower than P deployments. Initial Attack deployments contain the highest intensity activities performed by FireRangers and contain less opportunities for recovery given the urgency inherent in this type of fire deployment.

The findings from our HRV data analyses only represent physiological reactions to specific working conditions during the device-wear period. However, the results provide interesting insight into the varying physiological demands specific to FireRanger deployment type and are valuable considerations in the development of fatigue mitigation strategies.

Fatigue Mitigation Recommendations

There are three distinct periods within an annual fire season: pre-season, in-season, and off-season. It is therefore suggested that FireRanger activities mirror that of professional athletes, who have a similar, seasonal workload. The Ministry of Natural Resources and Forestry (MNRF) acknowledges that FireRangers are occupational athletes, evidenced by the continuing evolution of the annual FireRanger pre-season fitness evaluation, established in 1997[27], and the adoption of the "Commit to be Fit" program in 2014. The Canadian Physical Performance Exchange Standard for Type 1 Wildland Firefighters (WFX-FIT) is the annual, pre-season fitness assessment for FireRangers, which closely mimics the jobs tasks performed during fire deployment[22]. This test is used to confirm whether FireRangers have the strength-endurance capacity to endure the physical demands of a fire season[22], emulating pre-season athlete assessments in professional sports. To assist FireRangers with preparation for the WFX-FIT, the Canadian Interagency Forest Fire Centre (CIFFC) has made available resources containing wellness strategies and a comprehensive 6-week fitness program with detailed instructions[23]. With regard to in-season fitness maintenance, the MNRF implemented the "Commit to be Fit" initiative in 2014. Within this program, FireRangers are given one hour, during shifts spent at base, in which to perform structured fitness activities. Implementation of this program is a positive step towards the promotion of in-season fitness. Absent in this program however are recommendations for performance- and recovery-promoting nutritional practices[22].

Adequate energy intake and proper nutritional practices are also essential for maintaining performance levels[3,14,15,19,24,47,54] and are therefore an essential component of comprehensive fatigue mitigation and injury prevention strategies. As indicated in this study, FireRangers are consuming inadequate kilocalories, relative to the demands of their work activities while also under consuming carbohydrates[3,36,54]. Additionally, FireRangers' micronutrient consumption may negatively affect their performance and health. It is therefore recommended that the existing resources available to FireRangers be revised to include strategies to achieve adequate energy balance through quality nutritional practices[3,54].

Limitations and Future Directions

While this study measured a number of variables known to relate to an individual's potential for fatigue, and supports the use of a methodology capable of simultaneously monitoring energy balance, physiological responses, and nutritional quality, there are numerous other factors which were not evaluated. Future research should seek to evaluate factors such as sleep quality, subjective fatigue, and as it is important to consider the full spectrum of factors that impact fatigue in order to best develop comprehensive fatigue mitigation strategies for FireRangers.

A concern during participant recruitment was the potential for individuals with an interest in fitness, health, and wellness to be more likely to volunteer their participation. Given the self-reported activity level of the participants below, which would be indicative of athletes training for competition[30], as well as the observed under-consumption of calories and deviation from nutritional guidelines[3,36], this does not appear to have been a concern in this sample.

Conclusions

FireRangers may be experiencing physical and a nutritional fatigue based on the energy demands, nutritional practices, and differing physiological responses specific to their varying deployment types. As discussed, the existing initiatives targeting FireRanger fitness and wellness are promising; however, there remain opportunities for improvement in terms of in-season fitness maintenance and inclusion of additional resources to promote quality nutritional practices for optimum athletic performance. Additionally, this study provides support for the use of a methodology capable of comprehensively evaluating the aforementioned variables in free-living contexts without the need for researcher presence.

Conflict of Interest

The author's have no conflicts of interest to report.

Author Contributions

AR, SD, CL, and ZM were involved in the conception and design of the study AR and ZM recruited participants and collected the data. AR was responsible for data/statistical analysis and interpretation, and drafting of the article manuscript. AR, SD, CL, TE, and AG were involved in editing of the manuscript. All authors read and approved the final manuscript.

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Chapter 4

4 General Discussion

4.1 Data Collection Methodology

4.1a Heart Rate Variability Monitoring

Developing data collection methodologies that would allow comprehensive assessment, simultaneously, was critical to the success of this thesis. Testing entailed several aspects of compliance from FireRangers, the most critical of which, was the successful wear of a Heart Rate Variability (HRV) monitor. The researchers selected the Zephyr Bioharness3 as the HRV monitor-of-choice as it was designed to meet the environmental needs of worker populations such as wildland firefighting[105]. FirstBeat Bodyguard2 monitors have previously been used for free-living monitoring of subjects[80]; however, it was identified early on that these devices would 'slip-off' due to body sweat. Early piloting of FirstBeat monitors in the 2013 fire season amongst FireRanger volunteers confirmed that these monitors would not be appropriate for use in the Canadian forest fire-fighting environment. Based on feedback from these FireRangers regarding use of the Bodyguard2 monitors, it was determined that the electrode-based nature of the devices was incompatible with the level of perspiration generated by FireRangers as well as the amount of necessary clothing and equipment worn by FireRangers that is constantly moving and shifting on top of the device. This feedback led to the conclusion that the risk of device malfunction and data loss from water and environmental damage as well as electrode detachment was too great and that another device would have to be utilized. Zephyr BioHarness3 units were advertised as waterproof, worn via chest strap, preventing slippage and were in fact designed for use in first responders. Data collected using the BioHarness3 units were analyzed using FirstBeat SPORT software; as this software both met the needs for the data analysis and was comparable, if not superior to other options available and researchers had previously used this software before. In order to confirm that software output was the same regardless of the devices used to collect the data, prior to data collection with the FireRangers the research team wore both devices simultaneously for several days and analyzed the software output. While it is recommended that this be expanded into a full validation study, despite the small sample size, the results showed that the software output from data collected using both devices was essentially identical (Appendix B) and therefore concluded that the BioHarness3 was appropriate for use in place of the Bodyguard2 and could be used with confidence.

While doubly-labelled water (DLW) is still the gold standard of estimating Energy Expenditure (EE) for free-living purposes[7], it does not allow for activity-specific EE analysis nor for the characterization of physiological conditions related to fatigue (i.e. physical activity, stress, and recovery); that HRV monitoring does. In addition, HRV monitoring is preferable for free-living estimation of EE since when using the Bioharness3, subjects can collect personal data independently and remotely from researchers. Whereas the DLW methodology, requires the regular and timely collection and processing of urine samples, in addition to the timed-dosing of the doubly, labelled water. The accuracy of HRV monitors and FirstBeat SPORT software for estimating energy expenditure, has been validated in the laboratory, compared to indirect calorimetry, across all physical intensities[34,73,80]. While it has been noted that the accuracy of HRV-based EE estimates decreases at low activity intensity relative to moderate to high activity intensities[73,80], the lack of disparity between HRV and IC measures of EE on a group level across all intensities supports this method across the full range of activity intensity[80]. Given that FireRangers perform tasks at work across the entire spectrum of physical intensities, and that data will be analyzed as a group, HRV monitoring was deemed appropriate for the purpose of EE estimation in a population of FireRangers.

4.1b Audio-Visual Food Logs

When planning the methodology with which FireRangers would collect data regarding their nutritional practices, the authors investigated the most recent methods employed in this field. Dietary assessment through photography has been found to be a viable method with which to accurately and reliably collect food intake data, relative to known values in controlled scenarios, while avoiding the aforementioned limitations documented with use of the now-dated self-report and dietary recall methods[51,66,67,68,103].

Our laboratory is particularly interested in evaluating food consumption under various real-life scenarios with the intent to develop meaningful policy or practice changes specific to nutrition. Our research group has previously conducted research on assessment of nutritional practices in various populations using photo analysis with success[30,37]. In the present study, our participants required portability and independent collection of data in the field, however we modified our methodology from photography to video to improve on the diary component of the data collection. Written diaries to describe food contents that are not visible, is time-consuming, which also means subject compliance will vary. For these reasons, it was decided that iPod Touches, with durable impact and water resistant cases, would be provided to each FireRanger, to serve as a user-friendly, easily accessible method of documenting all foods consumed, at the time of consumption through the use of the iPod's video *and audio* recording functions. This method allowed for both the visual identification of food items, *and* firsthand audio records of specific ingredients and portion sizes in foods where this information was not visually available.

4.1c Compliance and Future Methodological Recommendations

Despite engaging in multiple discussions with both FireRangers and MNRF Fire Management personnel to develop the study methodology such that it could be implemented without impacting FireRanger performance and completion of work-related duties, there were still issues with participant adherence to the data collection protocols throughout the 2014 fire season. After participants' first deployments, it was noted that many failed to fully follow the protocol; specifically, participants did not begin wearing the BioHarness3 upon waking in the morning nor did they accurately document all of their meals according to the requirements of the study. At this time, researchers met with participants to discuss the collection protocol and provide assistance accordingly. Compliance with the data collection protocol was varied amongst participants throughout the fire season, which prevented the collection of a 24h Energy Expenditure estimate using HRV monitors and ActiGraphs alone, as intended.

Participants inconsistently completed all individual aspects of data collection on a daily basis resulting in a fragmented data set. In terms of HRV data, participants collected 37 individual days of IA deployments with an average of 1.5 consecutive days, 36 individual days of P deployments with an average of 1.7 consecutive days, and 35 individual days of B deployments with an average of 1.5 consecutive days. The trend was similar for the food logs; in terms of food logs greater than 3-days in length, the average for the 6 food-logs from P deployments was 4.2 consecutive days, and 4.7 consecutive days for the 7 B deployment food-logs. These values reflect deployment lengths ≤25% of the maximum allowable according to the existing working time guidelines[5]. This lack in consecutive days of complete data relative to the maximum working time guidelines impacted the research in that the ability to draw conclusions regarding the effect of extended deployment length on energy balance and physiological state (physical activity, stress, recovery) was lost. Fortunately, sufficient individual days of data were collected for each deployment type such that comparison of daily demands could still be performed.

Aside from compliance issues, this study indicated positive support for use of HRV monitoring in occupational settings. Prior to use of HRV monitoring for free-living energy expenditure (EE) estimation in FireRangers, accuracy of HRV-based EE estimates was validated in laboratory settings relative to the gold standard of indirect calorimetry (IC)[80]. This validation study also indicated that during extended periods of free-living activity, EE estimates did not differ significantly based on the level of device calibration. Lacking in this study however was validation of HRV-based EE estimate accuracy in free-living scenarios relative to a gold standard measure, therefore it is recommended that future research be conducted to validate HRV-based EE estimates during free-living activity through comparison with doubly-labelled water (DLW)[7].

4.2 2014 Fire Season

It is important to note, when interpreting the results and participant compliance, that the 2014 Ontario fire season was the least active in recent history. There were 303 fires in Ontario affecting 5386 hectares of land, which pales in comparison to the average for the past 10-years of 1098 fires per year affecting 110,895 hectares of land[6]. The 2014 fire season lacked in both intensity of local fires and consistent periods of FireRanger deployment, which was not advantageous for this study design. The aforementioned lack of consecutive days of complete data sets can therefore be largely attributed to the lack of fires that FireRangers working out of the Sudbury FMH were deployed to. While the number of consecutive days of data collected was far less than the maximum deployment length, the data is still realistically reflective of deployment lengths by FireRangers throughout the 2014 fire season. There was simply a lack of fires requiring FireRangers to consistently cycle through the work/rest guidelines. Fire intensity during the 2014 fire season was also low. The fires that FireRangers were deployed to were of intensities far below the magnitude of past fires such as Timmins 9 that accounted for 40,000 of the 54,000 total hectares affected by fire in Ontario during the 2012 fire season and took a total of 8,100 person-days to bring under control[38]. The inconsistency of fires throughout the 2014 fire season inevitably led to inconsistent data, therefore the ability to draw meaningful conclusions at the group level regarding the physiological effects of fire deployment both early and late in the season was lost. The initial plan was to compare early season deployment to late season deployment, with the mid-point of the season being set as July 1st. Data for IA deployments was collected entirely in the early-season, and data for P deployments was collected entirely in the late-season. An additional point of relevance is that the P deployments were located entirely in western Canada, as there were no P deployments in Ontario. Days spent at the FMH (B deployments) were fairly consistent throughout fire season, however all data in this category was collected in the late-season. This trend in the data can largely be attributed to the late start to the fire season, as there was still snow on the ground when the researchers were meeting with FireRangers to recruit participants in April 2014. Overall the environmental conditions in Ontario were not conducive to fire consistency through the 2014 fire season, and therefore while the data collected were insufficient to allow early and late season comparison it accurately represents the distribution of fire deployments throughout the 2014 fire season. Ultimately, the data provided valuable insight into the demands that FireRangers endure within the various types of fire deployment, irrespective of the fact that it was the least active fire season on record.

4.3 Energy Expenditure/Intake/Balance

4.3a Energy Expenditure

Analysis of HRV data using FirstBeat SPORT software provides a substantial amount of information regarding the energy demands of specific types of forest fire deployment. Important to consider when interpreting the observed energy expenditure values is the aforementioned lack in fire intensity during the 2014 season. The lack in fire severity meant that while physically demanding fire suppression activities were still being performed, they were interspersed with frequent, sedentary rest periods, thereby lowering average hourly energy expenditure values (EE_{1hr}). EE_{1hr} is representative of EE for the 2014 fire season, however it is not representative of EE specific to the physically demanding tasks FireRangers perform. Therefore, it was decided that the highest 1-hour EE ($EE_{high\text{-}1hr}$) from each day of data collected would also be considered for contextualizing *deployment-specific* EE. $EE_{high\text{-}1hr}$ provided a more realistic representation of EE during acute fire suppression activities. Finally, for further investigation into the most acute energy demands contained in fire suppression activities, participants' peak EE (EE_{peak}) for each deployment type was translated into its corresponding MET value (kcal/min → kcal/kg/hr) and compared to the known energy demands of various activities selected from the Compendium of Physical Activities[8]. EE_{peak} provided insight into the *highest* intensity activities of forest fire suppression. The EE_{peak}-MET values for fire deployments ($EE_{peakIA} = 11.3 \pm 1.6$ METs and $EE_{peakP} = 9.9 \pm 3.2$ METs) and days spent at the base ($EE_{peakB} = 8.1 \pm 3.4$ METs) are comparable to the values documented for structural fire fighting activities (7-9METs), competitive soccer and ice hockey (10METs), and cross-country running (9METs)[8]. These similarities indicate that the work activities performed by FireRangers compare to some of the highest MET values documented in the Compendium of Physical Activities[8]. During an average to high intensity fire season, we anticipate that the time spent performing activities equivalent to EE_{peak} values would substantially increase and is therefore an indication that FireRangers need to be physically prepared for such high intensity activities.

Also important to consider are the differences in energy demands across deployment types. EE_{1hr} and $EE_{high\text{-}1hr}$ were found to differ significantly across all deployment types, trending downwards from IA to P to B. This trend is expected given the duties performed within each deployment type. This trend is also similar to that observed in a study conducted by Rodriguez-Marroyo that found direct attack fire suppression (<100m away from fire) was of higher intensity than indirect attacks (>100m away from fire)[81]. Direct attacks are similar to IA deployments and indirect attacks are similar to P deployments, and the differences in intensity between these deployment types support the findings of this study. There was no significant difference between EE_{peakIA} and EE_{peakP} although both were significantly higher than EE_{peakB}. These particular findings were expected given that IA and P deployments involve fire suppression activities whereas B deployments involve activities related to preparation for fire deployment. Peak energy expenditure values for all deployment types were also found to be equal to or greater than the peak energy expenditure values of forest firefighters in the study by Heil and colleagues[46].

These results highlight the fact that FireRangers perform duties across the spectrum of physical activity intensities, and therefore must also possess the physical capacity to perform work-related duties comfortably and safely across this spectrum. Forest fire fighting involves a variety of full-body movements, requiring simultaneously: strength, endurance, and balance. The MNRF has made progress towards ensuring FireRangers are physically prepared for these demands[23,31]. These results support the recommendation that fitness initiatives, designed to improve FireRangers' abilities to perform competently across the range of activity intensities, be developed further.

To examine the relationship between the daily energy demands of forest fire deployment and resulting fatigue, deployment-specific, 24hr EE was estimated. Since continuous HRV monitoring was not possible, 24hr EE estimation for each deployment type was estimated using a combination of HRV data, sleep time data, and MET values from the Compendium of Physical Activities[8]. The observation of an average 363.9 ± 61.21min/night of sleep is consistent with the amount of sleep obtained by Australian wildland firefighters[96,97]. Daily EE during forest fire deployment (EE_{IA24hr} – 4538 ± 1006.3kcal/day and EE_{P24hr} – 4021 ±1164.8kcal/day) was significantly higher than days spent at the FMH (EE_{B24hr} – 2842 ± 649.9kcal/day). No significant difference was found between EE_{IA24hr} and EE_{P24hr}, although the former was ~500kcal/day greater than the latter. Both EE_{IA24hr} and EE_{P24hr} however indicated that the daily energy requirements of forest fire deployment are substantially greater than the energy demands of activities performed while stationed at the FMH. It is important to keep in mind that during seasons of higher intensity and workload, days spend at the FMH would involve greater energy demands related to equipment maintenance and other activities involved in preparation for fire deployment. EE values of >4000kcal/day during forest fire deployment indicate that Ontario FireRangers have energy demands similar to those seen in military personnel[36,49,90], competitive athletes[32,76,100], and forest fire fighters in other areas of the world[46,82]. The similarities between 24hr EE estimates based on data from Ontario FireRangers and those seen in other studies also provide support for the estimates as reasonable representations of EE during forest fire deployment; despite the conservative nature of our 24hr EE estimates. Given the low demands of this particular fire season, these 24hr EE estimates are possibly lower than what would be expected during an average or above-average intensity fire season. Despite this, both EE_{IA24hr} and EE_{P24hr} are indicative of the high energy demands inherent in forest fire fighting and a potential source of FireRanger fatigue. These data also provide support for the consideration of Ontario FireRangers as occupational athletes.

4.3b Energy Intake

Assessment of energy intake was key to the understanding a potential contributor to fatigue amongst FireRangers. Average daily EI during P and B deployments was 2945 ± 888.8kcal/day and 2433 ± 570.8kcal/day respectively, and did not differ significantly. These values are consistent with kilocalorie consumption rates of Canadian adults in the age range of the participating FireRangers[86]. However, they are relatively low compared to recommendations for moderately active adults in the same age range (~3000 kcal/day)[45]. Having established that fire suppression is a high-intensity activity; the importance of achieving adequate energy intake to match these physical demands cannot be overstated. The low EI observed during P deployments is particularly concerning, given the observed energy demands in this type of deployment, which are substantially greater than daily living activities (BMR_{act} = ~3000kcal/day). Insufficient caloric intake therefore presents a potential source of fatigue, as it has been shown that extended periods of negative energy balance impact physical performance[4,49,77]. Also of concern is the low EI during B deployments. Despite the lower energy demands while at FMH, these workdays serve as an opportunity to replenish energy stores and recover physically from previous fire deployments[39,87]. This finding indicates that days spent at the base are instead serving to maintain, and potentially augment, fatigue levels.

Knowledge of the food supplies FireRangers receive during IA deployments, and previous research on the consumption patterns of forest fire fighters[72], allowed estimation of energy intake during IA deployments. EI_{IA} was notably higher than both EI_P and EI_B, even when applying the 80% consumption rate to the IA food supplies (EI_{IA80}). The total amount of energy available to individual FireRangers during IA deployments (EI_{IA}) is therefore fortunate given the noted increase in energy demands compared to the other deployment types, however EI_{IA80} is still less than the daily energy demands of IA deployment. Given that IA deployments contain the most hazardous and physically demanding conditions of all deployment types, they therefore require FireRangers to be in optimal operational condition. The effects of low energy intake are addressed further in the discussion on energy balance to follow (4.3c).

The fashion in which food is supplied to FireRangers during each specific deployment type is a key factor in determining their daily EI and ability to perform demanding physical activities[28,72]. Cuddy and colleagues showed that self-selected work output among forest firefighters was increased when food was consumed regularly throughout a day of forest firefighting activities[28]. Additionally, Montain and colleagues studied the differences in physical activity when forest firefighters received equivalent rations in two different forms, meal-based and snack-based (meal ready-to-eat – MRE & first strike ration – FSR)[72]. Both of these studies showed that snack-based rations, consumed throughout the day, were more effective at sustaining work output relative to meal-based food intake. The food supplies FireRangers received during initial attack and project fire deployments resemble a hybrid of FSR and MRE. IA food supplies must be mobile at a moments notice and are therefore comprised of preserved dry and frozen foods that are easily transportable and require little-to-no preparation time. FireRangers during P deployments typically consumed a sit-down breakfast, obtained a ration pack for the day, and consumed a sit-down dinner following their shift. The ration pack typically contained items suitable for snacking (i.e. sandwiches, fruits) throughout work-related activities, in line with the recommendations of the previously discussed research[28,72]. The style in which FireRangers received food during initial attack and project fires present reasonably effective methods by which to provide FireRangers with adequate energy intake, however they may be augmented in several ways. This topic will be discussed in detail in 4.6a, 4.6.b, and 4.6.c.

4.3c Energy Balance

Key to the level of fatigue experienced by an individual is whether they consistently match their energy intake to the energy demands they experience on a daily basis[4]. Analyses of all deployment types (IA, P, and B) revealed a daily negative energy balance. The only scenario in which a positive energy balance was possible was when FireRangers consumed 100% of the food supplies available to them during IA deployments; however, this is unlikely given the observed low energy intake during project fires and days spent at base. These results are also consistent with those of previous research on forest firefighters. Ruby and colleagues showed a daily, negative energy balance of ~550kcal/day[82]. Montain and colleagues also showed that the caloric intake of foods supplied to wildland firefighters did not match the energy expenditure of the wildland firefighters in other studies[46,72,82]. Acutely, negative energy balance can result in decreased physical performance in terms of strength and endurance as well as increase risk of fatigue via reduced alertness and concentration[4]. These acute effects are not advantageous for FireRangers who must perform optimally on a day-to-day basis in order to adequately suppress fires while maintaining their safety. Chronic effects of daily, low energy intake may include weight loss, muscle wasting, decreased strength and endurance performance, decreased immune function, decreased energy levels and alertness[4]. Hoyt and Friedl reviewed existing literature on high energy-expenditure coupled with low energy intake over extended military training exercises days (from 2-60days), athletic events (22days), and adventure expeditions (86 & 95 days)[49]. They found that individuals consistently exhibited weight-loss and reductions in physical performance, as well as undesirable endocrine and immune responses[36,49]. Interestingly, Nindl and colleagues[77] noted that 5-weeks of light physical activity and open food consumption, following the 8-week US Army Ranger training course, recuperated decrements in physical performance and weight-loss. FireRanger's 18-day maximum deployment (including travel time) is less time, however the 2-day minimum rest before potential full re-deployment poses an interesting quandary. That is that cycling deployments can continue for the full-length of a fire season (i.e. 4-6 months) and may therefore in total, provide insufficient time to recover from the effects of consistent, negative energy balance. Ideally, prolonged, negative energy balance can be avoided by FireRangers and any potentially negative health effects mitigated, ensuring that these effects do not compound over consecutive deployments. Given that adequate energy intake is the most modifiable determinant in the energy balance equation, recommendations regarding food intake strategies need to be considered (4.6a, 4.6.b).

4.4 Physical Activity/Stress/Recovery

In addition to providing measures of energy expenditure, HRV analysis also provided insight into the physiological reactions of FireRangers during discrete working conditions. Although there is no consensus on the exact definition of stress, it can be physiologically defined by the reduced recovery of the neuroendocrine reaction and sympathetic dominance of the autonomic nervous system function, whereas recovery is characterised as parasympathetic dominance[35,60]. HRV can be used to assess autonomic nervous system responses during free-living activities[2,3,35]. Analysis of the HRV data in FirstBeat SPORT software produced reports detailing the percentage of log time spent in periods of: physical activity, stress (sympathetic activity), and recovery (parasympathetic activity), and other[35]. While this method is limited in that it does not directly measure autonomic nervous system responses, the association between autonomic nervous system activity and HRV has been validated through laboratory studies involving induced autonomic blockades[35,69] and is accepted to reflect autonomic nervous system activity[35,89].

4.4a Physical Activity

Increased daily physical work demands have been shown to increase the potential for fatigue and injury[14,29,85,87]. While not statistically significant (p=0.055), physical activity was observed to fill a larger percentage of average wear time during IA deployments (8.9 ± 3.66hrs/shift and 22.5 ± 10.33% of wear time) than P deployments (11.5 ± 2.54hrs/shift and 16.4 ± 11.70% of wear time). When also considering the differences in energy demands between IA and P deployments, FireRangers perform higher intensity activities for a larger portion of their IA shifts and are therefore at increased risk of fatigue and injury[85]. In a review of injury rates among occupations categorized from high to low intensity, Smith and Mustard[85] found that between 1990-2000, injury rates decreased with decreasing workplace physical demands. It is important to note that both types of fire deployment had significantly greater Physical Activity (IA: p=0.000 and P: p=0.002) than B deployments (10.6 ± 2.37hrs/shift and 8.3 ± 6.00% of wear time). The models of both Sonnentag[87] and Bakker[14] indicate that heightened workplace physical demands lead to fatigue and the potential for negative outcomes (i.e. injury). Further to this, Dick and colleagues[29] provide evidence indicating that heightened physical workload is related to the development of musculoskeletal disorders. While B deployments still involve performing manual labour in preparation for fire deployment, the low amount of physical activity relative to fire deployments provides FireRangers an opportunity to rest from the intense physical demands of fire suppression activities. This finding is supported by the observation by Vincent and colleagues[97] that Australian wildland firefighters exhibit "activity synergy" where performance of low-intensity activities on a given shift increases self-regulated higher-intensity physical activities on the subsequent shift. Australian wildland firefighters have also been observed to be able to maintain task performance and subjective ratings of perceived exertion on consecutive shifts even under conditions of sleep restriction[97,98]. Interestingly, the observation that firefighters reduce their activity during periods of non-physical work when sleep-deprived[98] is a potential strategy used by firefighters to maintain performance and cope with lack of sleep over consecutive shifts. Despite being able to self-regulate their activity for maintenance of task performance, FireRangers may still be experiencing factors related to underlying physiological fatigue.

4.4b Stress

In addition to physical demands, sustained periods of physiological stress and prolonged sympathetic activation are related to fatigue and negative health outcomes[21,35,39]. Stress was observed to be significantly lower during P deployments (4.6 ± 6.00%) relative to IA deployments (15.8 ± 13.91%) ($p=0.000$). This finding is understandable given the inherent differences in these deployment types. IA deployments involve spontaneous deployment wherein FireRangers are in close proximity to uncontained fires in unpredictable and hazardous environmental conditions. The lower stress observed during P deployments can be explained by the predictability of work activities[14,87] that are performed in less hazardous and more consistent environmental conditions than in IA deployments. Increased workload and presence of workplace hazards have been established as predictors of stress and fatigue[39,87]. Interestingly, while lower than IA deployments ($p=0.089$) B deployments were found to contain higher stress (8.6 ± 14.63%) than P deployments ($p=0.298$) although these differences were not statistically significant. Given that the 2014 fire season was far below the norm in terms of fire deployments[6], the higher level of stress observed during B deployments can potentially be explained by increased anxiety over the lack of available work[35].

4.4c Recovery

To combat the potential long-term negative health outcomes resulting from prolonged sympathetic activity and stress, adequate recovery and periods of parasympathetic activity are essential[39,87]. Sonnentag and Zijlstra[87] indicate that in jobs with high demands and low control, such as wildland fire fighting, the need for recovery increases. Furthermore, Guerts and Sonnentag[39] describe recovery as a vital link in the relationship between stress and chronic health issues. In this study it was found that FireRangers exhibited significantly less periods of recovery during fire deployments (IA: 14.4 ± 18.96% and P: 32.3 ± 23.39%) relative to shifts at the Fire Management Headquarters (B: 63.3 ± 23.49%) (IA: $p=0.000$ and P: $p=0.000$). Specific to fire deployments, recovery during IA deployments was found to be significantly less than P deployments ($p=0.002$). The observation that FireRangers exhibit periods of recovery within IA and P deployments is positive in that periodic opportunities for recovery throughout shifts (internal recovery) supports fatigue mitigation and performance maintenance[39]. Furthermore, the finding that FireRangers spend the majority of time during shifts at the Fire Management Headquarters in periods of recovery is favourable for FireRanger recovery to optimal functioning prior to redeployment and prevention of chronic health issues[39].

4.4d Physiological Balance

The relative amount of time spent in periods of physical activity, stress, and recovery across deployment types provided interesting insights into how FireRangers respond physiologically to their various working conditions. The interplay between physiological responses to varying types of fire deployment are important to consider when determining if FireRangers may be at risk for developing fatigue[39,87]. The specific combination of daily physical exertion in stressful working conditions without opportunity for recovery prior to subsequent shifts is indicative of potential for development of fatigue[39,87], and is therefore more of a concern during IA deployments relative to P and B deployments given what has been indicated by our data. While these data do not allow determination of the degree to which the observed ratios of physical activity, stress, and recovery periods specific to each deployment type may be impacting FireRanger fatigue, there is however greater potential for fatigue development in scenarios in which individuals have less opportunities for recovery compared to scenarios allowing for adequate recovery and a return to baseline physiological status[39]. FireRangers' inherently intense and stressful working conditions with low job-control[39,87], as well as what has been indicated by data collected during the 2014 fire season, support the implementation of stress reduction and recovery strategies (4.6.f).

4.5 Nutritional Quality

4.5a Macronutrients

The video food logs provided valuable information on the nutritional quality of foods available to, and consumed by FireRangers throughout the fire season. The results indicate that for all deployment types %fat consumption exceeded the recommended range, %carbohydrate consumption was below the recommended range, and %protein consumption was within recommended range[44]. These findings are substantially different from the macronutrient profiles found in previous research on American forest fire fighters[72,82]**.** In terms of total daily intake of specific macronutrients, FireRangers do not meet the recommendations set forth by the

American College of Sports Medicine, Dieticians of Canada, and American Dietetic Association[4] and misalignment with these recommendations is an indication that nutritional quality requires improvement.

Protein: It is recommended that athletes consume 1.2-1.7g/kg of protein and 6-10g/kg of carbohydrates relative to body weight[4]. When comparing total macronutrient consumption values to average participant body weight FireRangers were found to consume 2.5g/kg, 1.9g/kg, & 1.8g/kg protein, but only 3.5g/kg, 3.4g/kg, & 2.8g/kg carbohydrates during IA, P, and B deployments respectively. It is unclear whether the heightened protein intake, compared to recommendations set forth for athletes, requires action. Health Canada guidelines state that maximal intake of protein is 2.0g/kg for athletes for meaningful performance-related outcomes; however, their guidelines contain no stated Upper Limit for protein intake meaning that there is a lack of definitive data on the harmful effects of heightened protein consumption[43]. Further to this point, research has been unable to establish any conclusive link between excessive protein intake and the most commonly theorized long-term health concerns: renal damage and enhanced calcium excretion, in healthy individuals[18,53,65,92].

Carbohydrate: Of significant concern is the lack of carbohydrate intake that was observed, which was less than half of the *minimum* recommended intake in terms of percentage macronutrient intake[4,44,52,75] for all deployment types. More importantly, total daily consumption of carbohydrates irrespective of deployment type (~200-400g/day) was found to be below athlete recommendations suggesting a minimum of 500g/day based on the average weight of participating FireRangers (6-10g/kg * 85kg = 510-850g)[4]. Given that carbohydrates are critical for sustaining performance during high-intensity activities[15,19,28,56], as well as prolonged low-moderate intensity activities; we believe that this lack of carbohydrate intake during fire suppression activities is a major safety issue for FireRangers. As activity intensity increases, so does reliance upon carbohydrates to produce ATP in order to create the energy necessary to maintain performance of the activity[95]. Carbohydrate depletion is rapid under these conditions and maintaining intensity is dependent upon carbohydrate stores[56]. Given the unpredictable nature of fires, a need to rapidly respond with high intensity (e.g. sprint) is critical; likewise maintaining carbohydrate stores in muscles and liver is also critical. During prolonged low-to-moderate intensity activities fat is the predominant fuel source[95], however, fat metabolism requires a constant steady infusion of carbohydrate to burn fat[84]. In the absence of carbohydrate, the body will draw from protein sources to continue the activity[25,64,102]. Given the demands placed on the muscles, and subsequent need to repair and build, using protein for fuel is not optimal and may compromise muscle recovery and repair[54]. Carbohydrate consumption following intense activity is critical because it replenishes muscle glycogen stores[16,54]. Carbohydrate consumption every 20-30 minutes during prolonged, low-to-moderate intensity exercise is critical, as this will conserve glycogen stores for high-intensity periods (potential emergencies) as well as spare protein, such that proteins can be used for muscle repair and remodelling[54]. The regular consumption of carbohydrates is a key outcome message from this thesis because Ontario FireRangers are often required to perform these physically demanding duties for up to 14 consecutive days.

Related to this, carbohydrate consumption following high-intensity exercise enhances testosterone production, reduces cortisol secretion and enhances insulin secretion[54,62]. Testosterone will enhance muscle building in response to physical activity, which will help FireRangers adapt to physical demands of the job. Reduced cortisol secretion reduces the risk for infection related to immune suppression[57]. Insulin secretion post-exercise enhances the uptake of consumed carbohydrate into muscle cells[48], replenishing glycogen stores as well as preventing muscle protein catabolism[22], and indirectly stimulates protein building within the muscle[91], thereby preventing overall muscle loss. For the variety of aforementioned reasons, adequate carbohydrate intake is essential for FireRangers.

Fat: Established recommendations state that fat consumption should not exceed 35% of daily macronutrient intake[4,44,52], however Ontario FireRangers were observed to exceed this recommendation across all deployment types. Simply using the proportion of fat consumed relative to other macronutrients can however be misleading. In a scenario wherein adequate carbohydrate consumption is achieved (6-10g/kg)[4] and protein and fat consumption are held constant, the percentage of caloric intake attributed to fat drops to a more acceptable, albeit still elevated, range (~20-40%). A more substantial reduction in the proportion of caloric energy consumed from fat is limited because fat contains over twice the caloric energy (9kcal/g) as the equivalent amount of carbohydrates (4kcal/g). Total daily fat consumption by FireRangers was found to be ~100-200g, however whether this amount is excessive or not is difficult to establish as there are no explicitly stated guidelines for total daily fat intake[44,52], aside from the 65g/day used for nutritional labelling based on a 2000kcal/day diet[42]. When considering the daily energy demands of FireRangers and based on this recommendation (i.e. 65g/day 2000kcal/day), for a 4000kcal/day diet fat intake should be approximately 130g, which is equivalent to the amount consumed by FireRangers aside from IA deployments in which fat consumption is heightened (200g/day). Excessive fat intake has been shown to result in both acutely[50,55,99] and chronically[52] undesirable cardiovascular consequences. Therefore, given that FireRangers are under consuming caloric energy relative to energy expenditure on a daily basis, and although fat consumption is an efficient method to consume adequate energy, it is recommended that carbohydrates be selected to fill the gap. However, if additional fat consumption is selected to account for the discrepancy between energy intake and expenditure, it is suggested that foods containing unsaturated fats be consciously selected in place of foods containing saturated fats in order to reduce the risk of cardiovascular health issues[74].

4.5b Micronutrients

Several micronutrients[43] were identified to be below or above recommended daily intakes. Specifically, we observed low: fiber, magnesium, potassium, vitamin D, and vitamin E intake; as well as high: cholesterol, phosphorus, and sodium intake, across all deployment types. Micronutrients have a variety of essential roles in the promotion of optimal health and performance.

Adequate fiber intake prevents constipation and promotes satiety by slowing the absorption of nutrients over a longer period, most importantly carbohydrates, throughout the gastrointestinal tract[52].

Magnesium, Vitamin D and phosphorus will be considered together as they all play key roles in bone turnover. Low magnesium, low vitamin D and high phosphorus can negatively impact bone density[47,76,88]. Phosphorus enhances the excretion of calcium and magnesium[88,101], both essential for building bone, and as bone is essentially the storage depot for these nutrients deficiencies are essentially ‘silent’ as bone is depleted to make up nutritional shortages. Vitamin D is the hormone, which regulates bone deposition[47], however, this nutrient is only conditionally essential, since it can be made in the skin with daily, adequate sun exposure. We predict FireRangers received adequate Vitamin D via sun exposure.

The combination of high sodium and low potassium intake is the most concerning with respect to this thesis and the goal of mitigating fatigue. This observation is not surprising given that the majority of adults in North America exceed recommendations for daily sodium consumption[1], and foods that do not spoil, as often required for sustained remote fire suppression activities, are often high in sodium[53]. High sodium intake coupled with low potassium intake is linked to high blood pressure[1], and because sodium is the principal extracellular ion and potassium is the principal intracellular ion, an overabundance of sodium, and low levels of potassium will lead to a) increased extracellular water levels; thereby dehydrating cells themselves and enhanced water losses, as the body tries to balance these ions and is forced to over-excrete sodium and therefore water. Given the high levels of physical activity under high heat conditions, FireRangers are already at an increased risk for developing heat stress, and adequate hydration is essential to prevent this. This imbalance of micronutrients will increase their risk for dehydration. Simple changes, such as selecting of low sodium items and high potassium items, including potassium-enriched beverages would readily solve this identified problem.

4.6 Fatigue Mitigation Recommendations

4.6a Meal Composition Strategies

Physical activity is known to blunt appetite[58,59], and is an important consideration given that FireRangers must consume enough food each day to match the energy demands of their fire suppression activities. Conscious structuring of daily food intake is therefore key to maintaining subjective feelings of satiety, and promoting physical performance and recovery[25,58,59,70,72]. As athletes structure their energy intake according to the time periods before, during, and following periods of physical activity[4,25] it is suggested that FireRangers adopt similar practices. Ideally, a high-carbohydrate meal should be consumed four hours prior to commencing physical exertion[25,54,61], however this may not be feasible for FireRangers who begin their duties first thing in the morning and continue for up to 16hrs. To account for their work structure, each evening on deployment FireRangers should consume a high-carbohydrate meal (~150-200g = 600-800kcal) in order to replenish muscle and liver glycogen stores[61], as well as including protein to provide additional performance benefits and promote tissue recovery[4,52]. It is however recommended that such foods be consumed within the hour following fire suppression activity in order to promote systemic glucose uptake[52]. Upon waking and in the hour prior to beginning fire suppression activities, FireRangers should consume a light breakfast (200-400kcal) in order to prevent hypoglycaemia and satiate feelings of hunger[25]. In terms of meal composition, as mentioned previously foods rich in carbohydrates should be the focus of food consumption however it is also suggested that protein be consumed as well, provided it is consciously distributed throughout the day for optimum benefits[4,25,52]. Balanced protein intake throughout the day is beneficial in that when consumed in conjunction with carbohydrates it is an effective way to maintain satiety and performance during activity[4,25,61] as well as promoting tissue recovery following activity[4,52]. As the existing level of protein intake exhibited by FireRangers already exceeds stated recommendations for athletes, and research remains inconclusive regarding negative health effects from this practice, it is advised that protein consumption during fire deployment not exceed the current level in order to reduce the likelihood of potential long-term health issues[18,52,65,92]. Aside from the discussed structure regarding meals surrounding periods of fire suppression activity, specific attention needs to be paid to the structure of food consumption during fire suppression as this may occupy up to 16 hours of a FireRanger’s day.

4.6b Snacking Strategies

Frequent food consumption (i.e. snacking) throughout the day is an effective strategy for successfully maintaining energy balance and performance throughout prolonged periods of physical exertion[4,25,70,72]. It is suggested that during periods of physical exertion >90min individuals consume 0.5-0.7g/kg of carbohydrates per hour[4,25]. An effective way to support frequent food consumption during fire deployment is to provide portable, lightweight, food supplies[70,72] and to promote regular snacking-behaviour of carbohydrate and potassium-rich foods (i.e. sports drinks, energy gels) every 15-20 minutes[4,25]. Food supplies during fire deployments are already provided in an easily transportable format that promotes snacking behaviour, however it is suggested that they be modified in terms of the items contained in the food packs. The current composition of the IA food packs is such that the contained foods possess sufficient energy stores and require minimal preparation. Additionally, during P deployments FireRangers were found to receive food supplies similar to a hybrid of the FSR and MRE style rations previously studied. The snack-based style of FireRanger food packs during P deployments is advantageous in terms of achieving adequate daily energy intake, however the results indicated that FireRangers are not achieving sufficient energy intake to match the demands of their work activities. As mentioned previously physical activity reduces appetite[58,59], therefore food items higher in energy density and nutritional quality (e.g. trail mixes, energy bars, fruits) are recommended in order to supply more calories and nutrients per eating period. Ideally, it is recommended that food supplies be structured in advance to meet the spectrum of demands relative to fire deployment intensity that FireRangers are to be exposed to. Refinement of the energy content in daily ration packs based on predicted fire severity and activity intensity will both provide FireRangers with adequate resources to fuel themselves for their duties while also allowing the MRNF to most efficiently allocate its resources. Effective intervention to prevent the negative energy balance observed during B deployments is more difficult to achieve since individuals are free to consume self-obtained food items and are not bound by the foods provided to them by the MNRF. It is therefore advised that FireRangers be educated about the effects of negative energy balance and the need for conscious structuring of their diet before, during, and following fire suppression activities.

4.6c Nutritional Quality Strategies

There is a distinct need for strategies focusing on improving the nutritional practices of FireRangers in terms of overall daily energy intake and macro- and micronutrient content. Each deployment type poses challenges in terms of strategies for nutritional improvement. As FireRangers have collective input over the foods selected to comprise the IA food supplies, educating the FireRangers about how to make positive nutritional choices is key (see 1.6.g). The existing FSR/MRE hybrid during P deployments is promising and presents an ideal structure in which to increase overall carbohydrate consumption and distribute protein consumption throughout the day to maintain performance and promote recovery[4,25,54,61]. Finally, during days spent at the Fire Management Headquarters (B deployments), FireRangers may adhere to their usual self-selected eating patterns. There is the opportunity to develop behavioural interventions aimed at improving nutritional choices in daily life in hopes that the habits will translate to better food choices and structured eating habits when presented with food options for deployment. FireRangers should be educated about how to choose nutrient-dense foods that meet carbohydrate and protein requirements, and are also higher in desirable micronutrients. Although food items for deployment need to be transportable, durable, and spoil-resistant, items that possess these qualities are typically processed/packaged foods with an inherently low-quality nutrient profile. Focus should therefore be given to educating FireRangers about how to select food items that meet their energy needs and also provide adequate micronutrients known to promote performance and health. It is also suggested that specific focus be given to educating FireRangers about how to lower sodium and increase potassium, fiber, vitamin D, and vitamin E.

4.6d Additional Energy- and Performance-Enhancing Strategies

Aside from providing FireRangers the educational resources necessary to increase kilocalorie intake and improve the quality of their nutritional practices, augmentation of food supplies with items containing performance-enhancing substances is warranted. Caffeine supplementation through caffeinated chewing gum within snack-based eating behaviours at regular intervals throughout the workday has been shown to maintain cognitive performance and work output in both military personnel and forest fire fighters[70,72]. Caffeine supplementation is also advantageous since it has been shown to induce fat metabolism[27], therefore muscle glycogen stores may be spared. An issue with this method however is the potential choking hazard of chewing gum while performing demanding physical activities. Dietary nitrate (NO_3^-) supplementation has also been recently studied in laboratory settings and has been shown to result in enhanced physical performance through reduced metabolic costs when consumed in adequate amounts on a daily basis in both athletes and recreationally active healthy individuals[20,63,94,104]. Additionally, blood pressure was found to be lower when blood plasma levels of nitrates are heightened[94,104] indicating positive implications for long-term health and disease prevention. Foods high in nitrates include leafy greens and beetroot[94], with the extracted juices of the latter being crafted into beverages high in nitrates that can be easily transported and consumed *ad libitum*. Both caffeine and nitrate supplementation are options that could easily be added to energy-dense food supplies designed to promote snacking behaviour. Consumption of branched chain amino acids is also advised. To promote muscle and tissue recovery, branched chain amino acids (BCAAs) have been shown to induce muscle tissue anabolism and prevent muscle tissue catabolism, with the additional benefit of reducing the amount of subjective fatigue experienced through a variety of physiological mechanisms[17,71,83]. As there is potential to provide FireRangers with effective and safe performance enhancing strategies outside of calorie containing food items, it is recommended that FireRangers be educated about these options and that they be made available during fire deployments.

4.6e Physical Fitness Recommendations

Fitness maintenance throughout the course of a fire season is an area that has been of interest in recent years, as evidenced by implementation of the WFX-FIT in 2012[23]. In addition, the 2014 fire season was the first in which FireRangers were provided a structured training program[13] to follow throughout the fire season. Research has indicated that activity-specific training programs hold promise in terms of injury reduction[79]. When an 8-week pre-season training program was implemented in seasonal tree-planters, comprised of activities mimicking those performed in the workplace, annual injury rates were subsequently reduced by ~40%[79]. It is therefore suggested that development of similar programs comprised of activities simulating those regularly performed by FireRangers and related to the most commonly observed mechanisms of injury, be developed as a potential way to reduce injury rates. For example, balance and core exercises can be used to target reduction of injuries resulting from slips, trips, and falls, as well as grip and upper body strengthening to target reduction of injuries resulting from equipment, machinery, and tools use[9,10,11,12]. The WFX-FIT already effectively mimics fire suppression duties for the purpose of deeming FireRangers as fit for duty prior to each season[23], and serves as an excellent template with which to expand pre-season training and develop additional in-season fitness initiatives. The CIFFC provides FireRangers with resources meant to provide a training template in preparation for the annual WFX-FIT assessment[24]. The existing resources include a 6-week fitness program meant to prepare individuals for the WFX-FIT test. However, the preparatory fitness program does not include progression from the suggested isolation exercises to more functional movements simulating those performed during fire deployment, and which comprise the WFX-FIT test[24]. Regarding in-season fitness, implementation of the “Commit to Fit” program provides FireRangers 1 hour during each shift at the base that is dedicated to structured fitness activities[13]. The structure of the program as it exists currently again lacks focus on functional movements relating to fire suppression tasks and the most commonly observed mechanisms of injury, but does however contain promising recommendations for flexibility and active recovery as well as the structuring of fitness activities based on deployment status[13]. Augmentation of the existing pre-season and in-season fitness programs to promote a focus on functional movements performed during the fire season has several potential benefits. Doing so would serve to reduce FireRanger injury incidence during the fire season, and prepare FireRangers for their annual WFX-FIT, thereby increasing the likelihood of remaining safe and healthy within demanding working conditions.

During the off-season, injury rehabilitation and recovery from the previous fire season is essential. It is advised that in the off-season FireRangers should perform structured activities to promote fitness maintenance and expedite injury recovery. Off-season fitness activities should be designed such that they can be completed with little to no equipment, as FireRangers may not necessarily have access to comprehensive fitness facilities. A compilation of accessible exercise routines that may be performed by FireRangers throughout the off-season is advised. The existing “Commit to be Fit” resources contain a comprehensive list of exercises requiring no equipment. We advise that these recommendations be reframed within a dedicated off-season fitness program specific to the months leading up to the preparation for the WFX-FIT and subsequent fire season. Ultimately, FireRanger injury rates have remained consistently high despite the continuing evolution of fitness initiatives, indicating the need to further expand the existing initiatives accordingly.

4.6f Stress Management and Recovery Strategies

In order to combat the potentially adverse effects of physical activity, physiological stress, and lack of recovery opportunities during IA deployments relative to other deployment types, it is recommended that FireRangers adopt structured, stress reduction and recovery promotion strategies, similar to the proposed structured, nutritional strategies based on athlete practices. There is a need to select strategies, which are accessible in remote locations, due to the nature of this job. Research has shown support for stress reduction and recovery practices in both occupational and competition settings[26,33,40,41,93]. Specific to occupational settings, Field and colleagues[33] found significant reduction in self-report measures of anxiety, fatigue, confusion, and depression, as well as increased vigour in a population of hospital employees after implementation of music, imagery, and muscle relaxation therapies. Similarly, implementation of a yoga workshop in office workers was found to reduce self-report measures of stress as well as upper body muscular tension and pain[41]. While the benefits of these strategies has been limited to indoor and office work settings[33,41], it is recommended that the efficacy of these stress reduction strategies be evaluated in demanding occupations such as wildland fire fighting. Various modalities of recovery strategies have also been studied extensively in populations of athletes[26,40,93]. Gill and colleagues[40] found that the use of low-intensity active recovery, compression garments, and contrast water therapy all significantly improved post-match recovery relative to simple passive recovery. Vaille and colleagues[93] found that contrast and cold water therapies were more effective than hot water therapy and passive recovery at maintaining exercise protocol performance over consecutive days. Interestingly in a review of the effects of contrast water therapy, Cochrane[26] notes that aside from promoting muscular recovery, contrast water therapy is also useful for neurological recovery from periods of sympathetic activation. While it is recommended that these accessible strategies be adopted diligently during IA deployments, given the low-intensity of the 2014 fire season, these strategies may also be advantageous for use during P and B deployments as their implementation requires little resource allocation and presents only potential benefits.

4.6g Educational Resources

Aside from direct intervention, it is recommended that informational and educational resources be developed for FireRangers that highlight the aforementioned strategies to promote optimal performance and recovery. The existing “Commit to be Fit” (C2F) document already outlines strategies for improving physical fitness[13] (1.6.f). C2F provides an ideal platform in which to add the proposed nutrition, stress reduction, and recovery strategies. It is recommended that sections dedicated to each of these areas be included in the Commit to Fit initiative, as informational documents. Furthermore, to better reach those individuals who may prefer to have information presented to them in visual formats, it is recommended that a series of short (<3min) informational videos, or “explainers”, be created and made available to FireRangers. Specific to the nutrition explainer videos, these videos should address energy balance, daily food intake structure, snacking strategies, carbohydrates, protein, sodium and potassium, vitamins and minerals, as well as the discussed performance-enhancing substances. Ultimately it is suggested that these resources be included in FireRanger pre-season training as well as be available at the

Fire Management Headquarters and on personal mobile devices for reference as needed throughout the fire season.

4.7 Conclusions

4.7a Summary

To reiterate, the purpose of this study was to a) evaluate the accuracy of HRV-based energy expenditure measures, and b) assess physiological determinants of FireRanger fatigue simultaneously. This research confirmed both hypotheses, indicating that HRV-based measures of energy expenditure are accurate in comparison to the gold-standard of indirect calorimetry, and showing that much like forest fire fighters in other parts of the world, Ontario MNRF FireRangers exhibit immensely demanding working conditions and inadequate nutritional practices, unique to each deployment type. The results of this study indicate that there is merit to the MNRF's hypothesis that the high injury rates of FireRangers can be explained, in part, by the development of fatigue from long deployments comprised of physically demanding duties coupled with inadequate nutritional practices.

In terms of physical exertion, the results highlight the need to treat FireRangers as occupational athletes since their work activities have energy demands greater than, or equivalent to, intense physical activities (calisthenics, cross-country running)[8], military personnel[36,49,90], competitive athletes[32,78,99], and forest fire fighters in other areas[46,82]. Interestingly, FireRangers also have an annual working season schedule similar to that of professional athletes. Their profession involves a discrete off-season period for a large portion of the year (October – March), wherein FireRangers are not required to report to the FMH on a daily basis and are free to fill their time with other work or recreational activities of their choosing. Leading up to the start of the work season, FireRangers, like professional athletes, are required to meet performance standards to be deemed eligible for duty[23]. The standard is such that they require FireRangers to maintain a reasonable level of fitness in the off-season, and are meant to ensure FireRangers are fit enough to endure the demands of an entire fire season. Upon meeting the performance standards, it is also imperative that during the fire season FireRangers maintain their capacity for optimum performance through continuing physical training, sufficient rest between periods of intense exertion, and quality nutritional practices. The inclusion of annual fitness assessment as a condition of employment in 1997 was a positive step by the MNRF in the promotion of FireRanger safety and wellbeing[31]. The WFX-FIT is comprised of relevant strength-endurance assessment through simulated job tasks[23]. According to the Canadian Interagency Forest Fire Centre, the "job is the test and the test is the job" and it is used to establish a FireRangers eligibility for National or Provincial deployment based on their performance (17:30min = Ontario standard; 14:30min = National standard)[23]. Despite the introduction of the WFX-FIT in 2012, injury rates among FireRangers continue to remain the highest of all positions within AFFES, with fatigue continuing to be cited by FireRangers as a causal factor for a large portion of injuries[9,10,11,12]. It therefore stands to reason that further structure is required to promote improved FireRanger fitness.

Aside from the findings regarding the substantial energy demands of FireRanger duties, the results of this study regarding FireRanger on-deployment nutritional practices indicate this as an area likely impacting the level of fatigue experienced by FireRangers. Low energy intake and poor nutritional quality relative to the demands of their fire suppression duties show that FireRangers are not adequately fueled calorically and nutritionally. Of particular concern is the low carbohydrate intake of FireRangers. With carbohydrate consumption relative to bodyweight at ~50% of the recommended intake[4,43,44,75], FireRangers may be experiencing decrements in performance that could be contributing to the occurrence of injuries. Strategies targeted at improving on-deployment and free-living nutritional practices are therefore highly recommended alongside additional fitness initiatives. Specifically, educational strategies to promote diligence regarding adequate daily energy consumption and proportions of macronutrients distributed effectively throughout the day[4,25,54,61] are recommended. The existing resources available to FireRangers in the forms of the preparatory resources for the WFX-FIT[24] and the MNRF's "Commit to be Fit" program[13] are excellent opportunities to build upon in the coming years to more comprehensively address FireRanger fitness and overall wellness. Data obtained during the 2014 fire season, albeit representative of a low intensity fire season provides support for the consideration of FireRangers as occupational athletes. Indication that FireRangers are exposed to high energy demands and exhibit inadequate nutritional practices during the fire season are causes for concern as fatigue has been commonly cited as a major contributor to FireRanger injury. Expansion of the existing fitness and wellness resources based on the needs indicated by this study is therefore recommended. It is also advised that further research be conducted to study the effects of these additional strategies in terms of potential reduction in annual injury rates among FireRangers.

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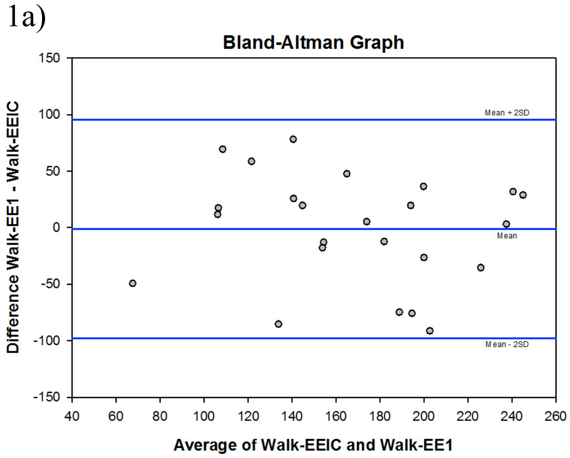
Appendices

Appendix A: Comparison of individual HRV and IC energy expenditure estimates.

Bland Altman Statistical Analysis were performed to examine the differences between the Energy Expenditure Estimates measured using Indirect Calorimetry and using the HRV with various HR_{max} and VO_{2max} estimates.

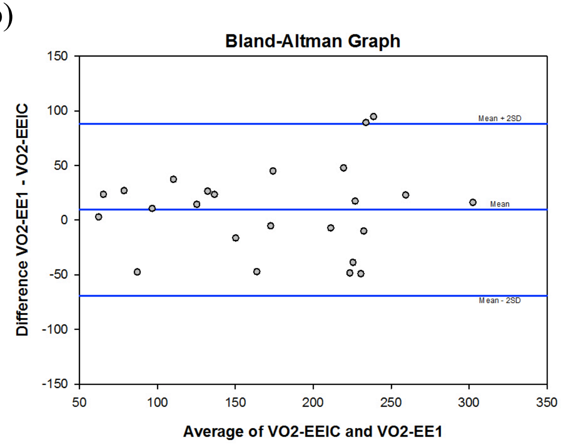
1) Individual differences between EE calculations between the EE1 (FB software w/ age-predicted HR_{max} and activity level (0-10)) and EEIC during (a) a low intensity, 30-minute Walk test and (b) a high intensity VO_{2max} test.

1a)



Bias = -1.1183
Std Dev = 48.3067
Limits of Agreement = -97.7317, 95.4950
Bias CI
95% CI = -21.5691 To 19.3325
Lower Limit of Agreement CI
95% CI = -133.1535 to -62.3098
Upper Limit of Agreement CI
95% CI = 60.0732 to 130.9168

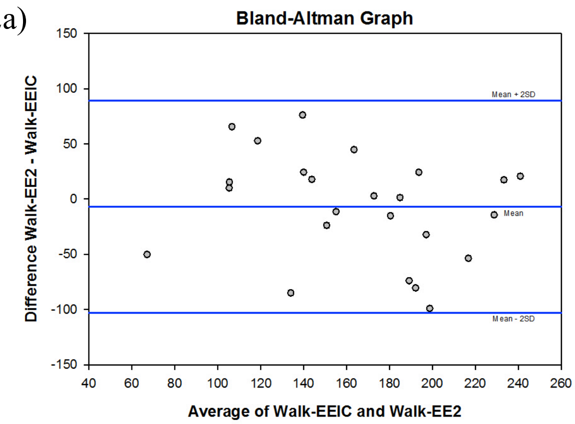
1b)



Bias = 9.6004
Std Dev = 39.3293
Limits of Agreement = -69.0583, 88.2591
Bias CI
95% CI = -7.0498 To 26.2506
Lower Limit of Agreement CI
95% CI = -97.8973 to -40.2192
Upper Limit of Agreement CI
95% CI = 59.4201 to 117.0981

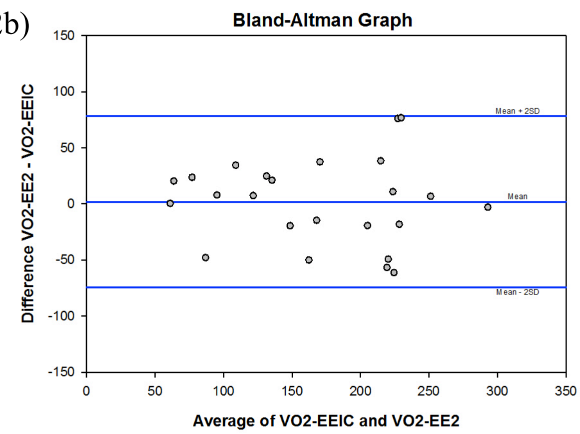
2) Individual differences between EE calculations between the EE2 (FB software w/ measured HR_{max} and VO_{2maxFB}) and EEIC during (a) a low intensity, 30-minute Walk test and (b) a high intensity VO_{2max} test.

2a)



Bias = -6.9021
Std Dev = 47.9566
Limits of Agreement = -102.8153, 89.0111
Bias CI
95% CI = -27.2047 To 13.4005
Lower Limit of Agreement CI
95% CI = -137.9804 to -67.6501
Upper Limit of Agreement CI
95% CI = 53.846 to 124.1762

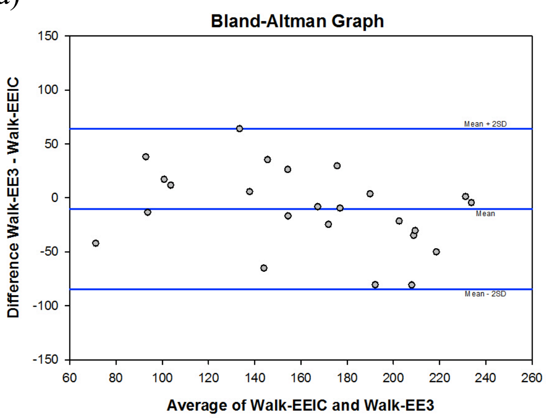
2b)



Bias = 1.9742
Std Dev = 38.1495
Limits of Agreement = -74.3249, 78.2732
Bias CI
95% CI = -14.1766 To 18.1249
Lower Limit of Agreement CI
95% CI = -102.2987 to -46.351
Upper Limit of Agreement CI
95% CI = 50.2993 to 106.2471

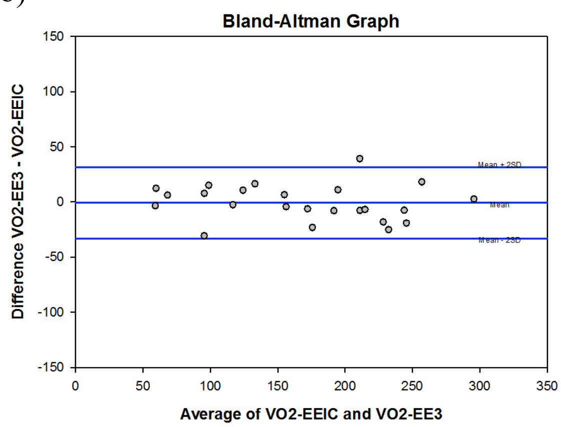
3) Individual differences between EE calculations between the EE3 (FB software w/ measured HR_{max} and VO_{2maxIC}) and EEIC during (a) a low intensity, 30-minute Walk test and (b) a high intensity VO_{2max} test.

3a)



Bias = -10.3271
Std Dev = 37.0881
Limits of Agreement = -84.5033, 63.8491
Bias CI
95% CI = -26.0285 To 5.3743
Lower Limit of Agreement CI
95% CI = -111.6989 to -57.3077
Upper Limit of Agreement CI
95% CI = 36.6536 to 91.0447

3b)



Bias = -.6675
Std Dev = 16.1545
Limits of Agreement = -32.9766, 31.6416
Bias CI
95% CI = -7.5066 To 6.1716
Lower Limit of Agreement CI
95% CI = -44.8222 to -21.131
Upper Limit of Agreement CI
95% CI = 19.796 to 43.4872

Appendix B: Comparison of Zephyr BioHarness3 and FirstBeat Bodyguard2 HRV (R-R Interval) data analysis in FirstBeat SPORT software

Intraclass correlations and paired samples t-tests were performed to compare Firstbeat SPORT software estimates of energy expenditure (kilocalories (kcal)) obtained from analysis of raw HRV data (R-R interval) collected during simultaneous wear of both the Firstbeat Bodyguard2 (FB) and Zephyr BioHarness3 (Z) devices.

Sample #	Log Time	FB – kcal	Z – kcal
1	17:15:00	1600	1561
2	35:30:00	3917	3905
3	21:15:00	2643	2631
4	18:30:00	2342	2153
5	11:15:00	1466	1384
6	10:15:00	2035	2038
7	02:10:00	1117	1191
8	06:30:00	1583	1553
9	11:35:00	2657	2655
10	13:45:00	2551	2433
11	11:30:00	1111	1083
12	02:45:00	687	708
13	11:35:00	620	611
Intraclass correlation		r = 0.998 p = 0.000	
Paired samples t-test		t = 1.702 p = 0.115	

Appendix C: Ethics approval forms

LaurentianUniversity
UniversitéLaurentienne

APPROVAL FOR CONDUCTING RESEARCH INVOLVING HUMAN SUBJECTS

Research Ethics Board – Laurentian University

This letter confirms that the research project identified below has successfully passed the ethics review by the Laurentian University Research Ethics Board (REB). Your ethics approval date, other milestone dates, and any special conditions for your project are indicated below.

TYPE OF APPROVAL / New X / Modifications to project / Time extension	
Name of Principal Investigator and school/department	Ayden Robertson & King, Kenneth
Title of Project	Investigating the Accuracy of Energy Expenditure using FirstBeat Heart Rate Variability Monitors and the Yamax PW-611.
REB file number	2012-09-01
Date of original approval of project	September 23, 2012
Date of approval of project modifications or extension *(if applicable)*	
Final/Interim report due on	September 23, 2013
Conditions placed on project	Final report due on September 23, 2013

During the course of your research, no deviations from, or changes to, the protocol, recruitment or consent forms may be initiated without prior written approval from the REB. If you wish to modify your research project, please refer to the Research Ethics website to complete the appropriate REB form.

All projects must submit a report to REB at least once per year. If involvement with human participants continues for longer than one year (e.g. you have not completed the objectives of the study and have not yet terminated contact with the participants, except for feedback of final results to participants), you must request an extension using the appropriate REB form.

In all cases, please ensure that your research complies with Tri-Council Policy Statement (TCPS). Also please quote your REB file number on all future correspondence with the REB office.
Congratulations and best of luck in conducting your research.

Susan James

Susan James, Acting chair
Laurentian University Research Ethics Board

LaurentianUniversity
UniversitéLaurentienne

APPROVAL FOR CONDUCTING RESEARCH INVOLVING HUMAN SUBJECTS
Research Ethics Board – Laurentian University

This letter confirms that the research project identified below has successfully passed the ethics review by the Laurentian University Research Ethics Board (REB). Your ethics approval date, other milestone dates, and any special conditions for your project are indicated below.

TYPE OF APPROVAL / New X / Modifications to project / Time extension	
Name of Principal Investigator and school/department	Ayden Roberston, Zach McGillis (SHK) Sandra Dorman, Celine Boudreau-Lariviere (SHK)
Title of Project	A multi-disciplinary approach assessing factors contributing to fatigue, to mitigate injury in wildland fire-fighters
REB file number	2013-07-08
Date of original approval of project	August 18, 2013
Date of approval of project modifications or extension *(if applicable)*	
Final/Interim report due on	September 30, 2015
Conditions placed on project	Please add the LU toll free number for your contact - it is the same number as for the REB – you can add in your extension if you would like to differentiate it from the REB number. Final report due on September 30, 2015

During the course of your research, no deviations from, or changes to, the protocol, recruitment or consent forms may be initiated without prior written approval from the REB. If you wish to modify your research project, please refer to the Research Ethics website to complete the appropriate REB form.
All projects must submit a report to REB at least once per year. If involvement with human participants continues for longer than one year (e.g. you have not completed the objectives of the study and have not yet terminated contact with the participants, except for feedback of final results to participants), you must request an extension using the appropriate REB form.
In all cases, please ensure that your research complies with Tri-Council Policy Statement (TCPS). Also please quote your REB file number on all future correspondence with the REB office.
Congratulations and best of luck in conducting your research.

Susan James

Susan James, Chair
Laurentian University Research Ethics Board